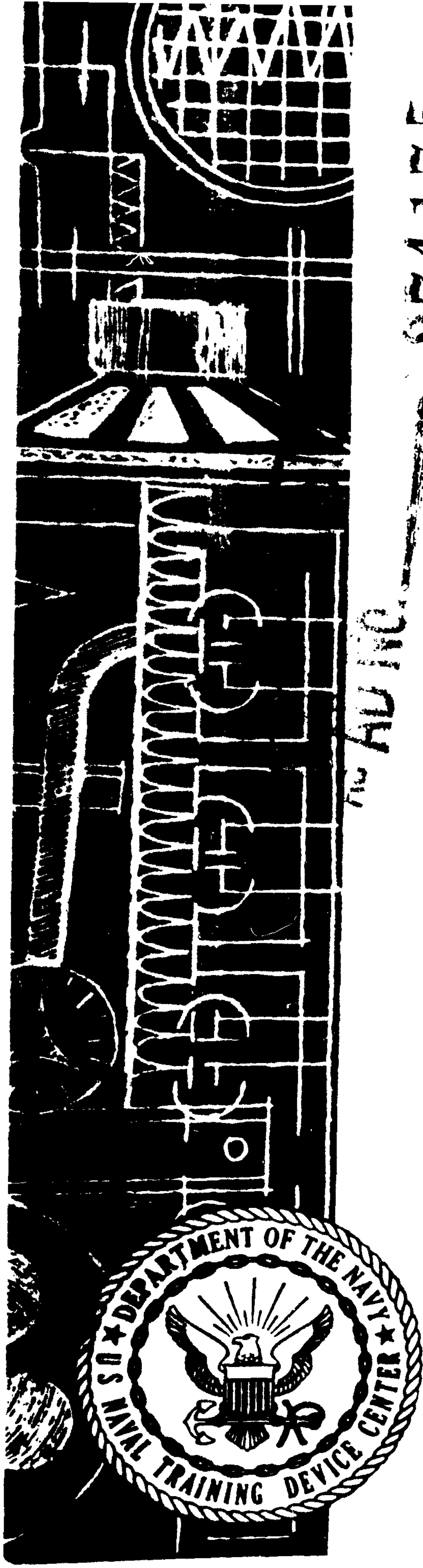

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INVESTIGATION OF DIGITAL SIMULATION OF AIRCRAFT SYSTEMS

U.S. NAVAL TRAINING DEVICE CENT

PORT WASHINGTON, L.I., NEW YO

Technical Report: NAVTRADEVCEN 772

INVESTIGATION OF DIGITAL SIMULATION OF AIRCRAFT SYSTEMS

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PORT WASHINGTON, NEW YORK

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ABSTRACT

INVESTIGATION OF DIGITAL SIMULATION OF AIRCRAFT SYSTEMS

Feasibility and methods of digitally simulating generalized aircraft systems were studied.

The following aircraft systems were considered: (1) wing flaps, (2) high pressure pneumatic, (3) hydraulic, (4) engine control, (5) fuel, (6) landing gear, and (7) electrical. To develop generalized systems, F4H-1, A4D-1, A4D-2, FJ-2, P6M, F9F, F3H-2N, and F-102A aircraft were studied.

Logical flow charts accompanied by the mathematical relations necessary to simulate digitally the indicated aircraft systems were prepared. It has been established that simulation of these aircraft systems can be greatly facilitated by the use of certain special devices. For a particular aircraft to be simulated, the appropriate inputs and the general simulation program could be combined by an assembly program to produce an optimized object program. Analysis of the fuel and electrical systems showed that simulation and generalization of these systems can best be accomplished by the development of an assembly program. A computer word (or words) having digits corresponding to the inputs and outputs of a system could be used to control most of the simulation logic. Incorporation of these special devices could significantly reduce equipment requirements and aid systems simulation.

FOREWORD

With the advent of digital flight trainers such as UDOFTT (Universal Digital Operational Flight Trainer), it became apparent that efficient programming techniques had to be developed to minimize cost and increase flexibility. One of the advantages of these trainers is their flexibility which make interchanging of an aircraft or one of the systems of an aircraft undergoing simulation fairly simple. In this respect, the ease and speed of program alteration becomes important. The purpose of this project was to develop techniques that will aid in eliminating the necessity of writing a program for each aircraft, and instead use one standard program and change the parameters describing the system characteristics whenever a substitute is to be made.

This project investigated the feasibility and techniques of digitally simulating the following aircraft systems:

1. Engine control
2. Landing gear
3. Wing-flaps
4. High-pressure pneumatic
5. Hydraulic
6. Fuel
7. Electrical

The equations describing these systems were derived in a generalized manner applicable to the simulation of many aircraft types.

The results of the project tends to prove the feasibility of this approach. The result of the program is a set of logical flow charts accompanied by mathematical relations necessary for the digital simulation of malfunctions and the possibility of using automatic programming techniques.

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SECTION II. INTRODUCTION

Under Contract N 61339-772 issued by the U.S. Naval Training Device Center, Goodyear Aircraft Corporation (GAC) has completed an investigation of the digital simulation of generalized aircraft systems. The final product of this program is a set of logical flow charts accompanied by the mathematical relations necessary for digital simulation of the following aircraft systems:

1. ~~Wing flaps~~
2. High-pressure pneumatic
3. Hydraulic
4. Engine control
5. Fuel
6. Landing gear
7. Electrical

The mathematical relations are appropriately presented in either equation or statement form. For both forms, GAC has attempted to maintain a generality of application to many aircraft. To facilitate digital programming and equipment design, these relations as well as the associated logic have been reduced to concise forms.

To avoid repetition and redundancy, the illustration of programming and simulation aids such as control words, steady rate, indexing, looping, etc., is given in considerable detail only in the first few systems presented. The repetitious detail is gradually decreased thereafter. It is believed that an average programmer could project these methods into the systems in which they are only indicated. In fact, these methods are merely suggested and are not intended as an imposition. They may be modified according to the option of the individual programmer.

The general methods of approach used in the study are presented in the Phase 1 report[a] and will not be reproduced here. In this report primary consideration is given to presentation of the end product of the study.

To demonstrate the simulation of different operational modes of the A4D and F4H systems, dotted and dashed lines are inserted in the basic flow charts to indicate the logic of these modes of operation. Preparation of input data for simulation of the A4D and F4H is illustrated in Appendices A and B.

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[a] GER-9729: Investigation of Digital Simulation of Aircraft Systems, Phase 1, Technical Report No. 1. Akron, Ohio, Goodyear Aircraft Corporation, 19 April 1960.

SECTION III. RESULTS, CONCLUSIONS AND RECOMMENDATIONS

This study has established the feasibility for and methods of digitally simulating the generalized aircraft systems listed above. It has also been established that simulation of certain systems can be greatly facilitated by the use of some special devices.

One such device is an assembly program. It could be used to optimize the general program for a particular simulation. It could even be used to set up the logic and actually develop the digital program to simulate a particular aircraft. It is evident from the material presented in the appendices that a considerable amount of effort would be necessary to prepare some of the generalized systems simulations for a particular aircraft. For example, the fuel system simulation would require the expenditure of considerable effort. The methods used in data preparation and the establishment of exact logic are quite lengthy because of the inherent nature of the system. To preserve generality and to avoid repetitious manual assembly, it is recommended that consideration be given to an assembly program. In this manner, complete optimization of the general simulation for a given aircraft can be performed automatically by a computer.

Another device is the control word. This is simply a computer word (or words) having digits corresponding to the inputs and outputs of a system. This facilitates the performance of the logic of a simulation since the computer need not perform arithmetic operations to perform the basic branching involved. Also, such a control word can be used to establish, automatically, a priority for simulating any given system.

Since the aircraft and their associated systems are quite different, the degree of generalization among the systems simulations varies. In any case, the simulations are general enough to cover several aircraft, including the A4D and F4H.

With the advent of more complex aircraft and corresponding training devices, future application of generalized systems simulations implemented by the above special devices appears to be a very worthwhile consideration.

This study has indicated that a digital computer with a capability of high-speed branching is needed. A feature enabling a decision to be made by testing a particular digit of a given computer word would allow the use of control words.

In addition to the principal requirement of high-speed logic, a time reference is also needed. This, of course, could be a nonreal-time reference if the computer, simulation, or other conditions so dictated.

The estimated memory capacity of the computer includes all storage used, whether for data, program, control words, address modification, etc. The required memory capacity for simulating the seven aircraft systems would be approximately 10,000 computer-word storage locations. This storage requirement was determined on the basis of the information presented below.

This number, a maximum, is based on the condition that the generalized aircraft systems be programmed for simulation as presented in this report. The basic concept is that only one general simulation program, although it may be large and complicated, need be written to simulate several aircraft. This concept will greatly facilitate changing from one aircraft simulation to another, since the same program would be used in either case. Only the input data and the electrical connection to the trainer cockpit need be changed when aircraft are changed.

This technique is in direct contrast to the present analog systems in which the entire training device must be manufactured when it is desired to simulate a new aircraft. Over a period of time, the cost of manufacturing new analog trainers will rise, while the cost of digitally simulating general aircraft systems will be reduced to the simple maintenance and operating costs of one digital computer. Also, the time to load new data into a digital computer and make general electrical connections is negligible compared to the time required to design, develop, and manufacture an analog device that will ultimately perform the same simulation.

Since most aircraft simulations will not require all parts of the generalized digital simulation program, it would seem informative to compare the computer storage requirements for simulating a particular aircraft with the general storage requirements previously mentioned. For example, two cases for the A4D will be considered: (1) it is estimated that 6000 storage locations would be adequate to simulate the systems discussed herein for the A4D, if the general simulation program were used, assuming that the entire general program is available to the simulation within the computer but that only those parts applicable to the A4D are used; and (2) if the general program or general flow charts are optimally assembled for the A4D so that only a specific program for that aircraft is available to the simulation within the computer, then 3500 storage locations should be adequate to simulate the systems discussed herein.

The basic difference between the two cases is that for the first case, a detailed general program would be used to simulate a relatively simple aircraft; in the second case, a special optimum program containing only the basic necessities for simulating a particular aircraft would be used.

The estimated computer speed required for a complete simulation cycle of seven aircraft systems is based on the total number of operations possible during a cycle. The types of operations are divided into the following groups:

Type of operation	Total number of operations by type
Logic	13,000
Addition and subtraction	7,500
Multiplication and division	1,000
Storing	4,000
Miscellaneous	500

It should be noted that an average operation time of approximately 2 μsec is necessary for a 50-millisecond (msec) cycle time.

The total number of operations during a simulation cycle is again based on a program that would result from programming the generalized flow charts and equations presented in this report; that is, the total number of operations per cycle for simulating the seven systems of the most complicated aircraft that can be simulated with such a program.

To make a comparison of computer speed requirements, the two methods for simulating the A4D defined by Cases 1 and 2 , above, will be considered again on the basis of a 50-msec cycle time. Average operation times of 10 μsec and 75 μsec should be adequate to simulate the A4D for Cases 1 and 2, respectively. It should be noted that reductions in computer requirements from the maximum values to the Case 1 values result from the relative simplicity of the A4D. Reductions in computer requirements from Case 1 values to Case 2 are due to the implementation of an assembly program. Thus, it becomes increasingly evident that assembly techniques should be investigated further.

It is believed that by implementing the assembly program, the number of operations for a simulation cycle could be significantly reduced. In some cases, a reduction by a factor of 10 might be expected in going from a Case 1- to Case 2-type simulation. A smaller factor, perhaps two, would apply to the corresponding reduction of storage. It is suggested that allowance be made for possible future expansion.

It should be noted that the above estimates are quite conservative and that only average programming is assumed. Moreover, the simulation of aircraft systems as presented in this report is intended to approach more closely the actual systems than many of the past simulation methods.

With competent programming and possible reduction of the present simulation to a less approximate one, considerable reduction of computer requirements could be experienced.

SECTION IV. DISCUSSION

A. Wing Flaps System.

The components and functions of a general wing flaps system are:

1. Part of the trailing edge of the aircraft wing that can be moved to modify the aerodynamics of the aircraft
2. The necessary mechanical connection to the wing
3. The actuating valves and cylinders that transfer hydraulic or pneumatic power to move the flaps
4. The electrical or mechanical pilot-operated controls
5. A flap position indicator.

More specialized systems may have electric motors to move the flaps, and some have a pressure relief or blowback feature that prevents flap extension at certain air speeds; in other systems, warning devices are activated by the improper use of flaps. All these features are included in the simulation.

Slat systems (part of the wing leading edge) that do not operate simultaneously with the flaps are not considered. It is assumed that only symmetrical flap extensions can be made since most flaps are mechanically connected for a given aircraft. In the event an asymmetrical extension is desired in the simulation, slight modifications in the routine will allow it to be repeated once for each individual flap with the appropriate inputs.

The student pilot can have access to any or all of the following controls and indicators, depending on the particular aircraft being considered:

1. Normal flap control, including "flaps up," "flaps down," and "flaps stop "
2. Emergency flap control
3. Flap position indicator
4. Flap warning device
5. Flap warning device circuit breaker
6. Flap position indicator and flap control circuit breaker

The insturctor has indicators similar to the pilot's, plus indicators for each pilot's and instructor's controls. The instructor can insert the following failures in the system during a simulation:

1. A complete system freeze, permitting the instructor to fix the flap position permanently, as long as the freeze switch is on
2. A normal fail, which will fail the normal flaps system; however, any available emergency system can be employed for flap movement
3. A circuit breaker fail, which turns off the pilot's circuit breaker
4. An indicator fail, which fails the flap position indicator only

In addition to simulating the basic general flaps system, incorporating the above features, the simulation procedure provides an output to aerodynamics and establishes the flap requirements of other systems.

The basic flow chart (see Figure 1) for the general flap system simulation is divided into 14 subroutines. The subroutines are composed of the branching, computations, etc., necessary to perform their particular phase of the simulation. A detailed description of each subroutine is given in Appendix A. A normal "flaps up" situation is illustrated in the basic flow chart by a dotted line for the A4D, while a normal "flaps down" situation is illustrated by a dashed line for the F4H.

B. High-Pressure Pneumatic System.

The pneumatic systems considered in the preparation of the generalized simulation range in complexity from simple stored pressure systems to completely automatic self-replenishing systems with compressor units. In any case, the principal functions of a high-pressure pneumatic system are to supply pressure to the actuators for those subsystems that require pressure and to provide outputs that indicate the operational and functional status of the main system.

The basic operations involved in various pneumatic systems are discussed briefly below. The components and functions common to all aircraft with high-pressure pneumatic systems are:

1. Ground filter and pressure gage for ground-charging the system
2. Lines and valves to transfer air pressure to the storage tanks

3. Pilot-controlled electrical or mechanical valves from which the associated actuators receive pressure from the storage tanks

Components and functions not common to all aircraft with high-pressure pneumatic systems are:

1. Compressor - Some aircraft are equipped with automatic compressor units that stabilize storage-tank pressure during flight. Associated with the compressor is a pressure transmitter that transmits system pressure to a cockpit indicator; a pressure switch that controls hydraulic or electric power to the compressor; a relief valve that prevents overpressurizing; a check valve to prevent pressure loss through the compressor during ground charging; a dehydrating unit; an engine bleed air filter; and electrical power to operate the pressure switch, transmitter, and indicator.
2. Priority valves - Particular aircraft with no compressor units distribute pressure, through priority valves, to selected actuators when insufficient pressure is available to meet all actuator requirements.
3. Low-pressure switch and associated warning lights.
4. Pressure regulators and reducers - Pressure regulators and reducers are used with acutators that require regulated or reduced pressure.
5. Application counters and indicators - Application counters and indicators are used to determine the number of times a particular actuator may be powered.
6. Circuit breakers - Electrical power to the compressor, indicators, and lights is controlled by circuit breakers.

Actuators or subsystems powered by the generalized high-pressure pneumatic system are:

1. Emergency flaperette
2. Emergency wheel brake (right)
3. Emergency wheel brake (left)
4. Emergency hydraulic pump
5. Emergency landing gear
6. Emergency flap extension

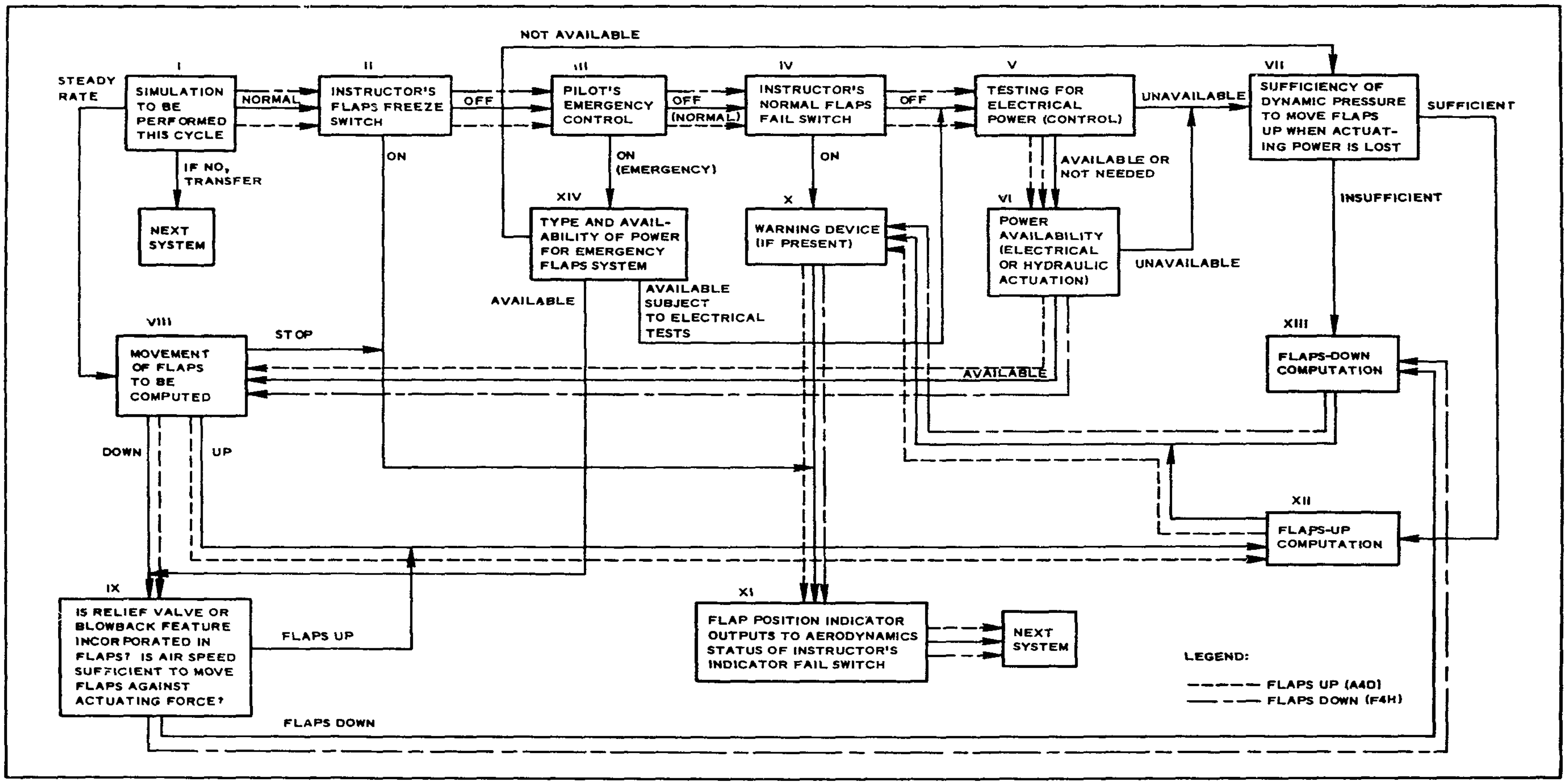

Figure 1 - Basic Diagram of Wing Flaps System Simulation

7. Emergency slat extension
8. Emergency spoiler holddown
9. Emergency canopy aft
10. Emergency canopy forward
11. Normal canopy
12. Drag chute extension
13. Rudder feel
14. Gun charge
15. Gun gas doors
16. Mine door seal
17. Nose gear strut extension

The emergency applications are often implemented by pressurizing hydraulic accumulators or by actuating cylinders. The A4D and FJ-2 have no high-pressure pneumatic system.

This simulation is designed to perform digitally the necessary calculations that describe the component functions discussed previously in this section, with the following exceptions:

1. Dehydrating unit
2. Filter
3. Pressure regulators and reducers

Subroutines are used in calculating outputs to subsystems, since in most cases the same basic equations can be used to describe compressed air movement from a particular storage tank to the associated actuator. In all but two or three special cases these "outputs to subsystem calculations" are combined into one general subroutine, which is computed once, with appropriate inputs, for each subsystem. Indexing is used to determine storage locations for the outputs and to proceed from one subsystem to the next.

In all the aircraft considered in this study, the pilot has little direct control of the pneumatic system. His only direct controls are circuit breakers. He may have pressure gages, low-pressure warning lights, or application counter gages that indicate the system status.

The instructor has indicators similar to those for the pilot, with additional ones that show him what has been done to modify the simulation. He has the following switches:

1. Ground charge switch - This switch allows a ground charge to be simulated at the instructor's option. It initially sets the system pressure, indicators, and storage tanks (bottles) to the normal operating level.
2. Indicator fail switch - This switch allows the instructor to fail the indicator only.
3. "Leak" switch - This switch permits the instructor to fail the main system pressure, but not individual bottle pressure, by inserting a leak. The magnitude of the leak or pressure decrement can be made proportional to the time the switch is on.
4. Circuit breaker fail - This switch fails the pilot's circuit breaker that controls electrical power to the air compressor. The pilot may reset the circuit breaker after the instructor's switch is turned off.

The basic flow chart for the general pneumatic system simulation is divided into 12 subroutines, as illustrated in Figure 2. A detailed description of these subroutines is given in Appendix B. The normal simulation of the F4H is indicated in Figure 2 by a dashed line.

C. Hydraulic System.

The principal functions of a hydraulic system are to supply hydraulic pressure to the proper actuators and to provide outputs to indicators that show the system status. The hydraulic systems of the aircraft studied vary in complexity from a simple single system to as many as four complex systems with an additional emergency system. All the systems studied were closed types. The components and functions common to all aircraft considered are:

1. Reservoirs are used as hydraulic fluid storage units to collect fluid from the return lines.
2. The pumps that pressurize the hydraulic system are engine-driven, variable-volume-delivery types. The volume output is a function of system pressure and engine rpm.
3. Check valves and relief valves are used to control the direction of fluid flow and to control maximum system pressure.
4. Accumulators are used between pumps and actuators to store hydraulic pressure. The accumulators dampen pressure surges and provide pressure to actuators when subsystem requirements are greater than pump output.

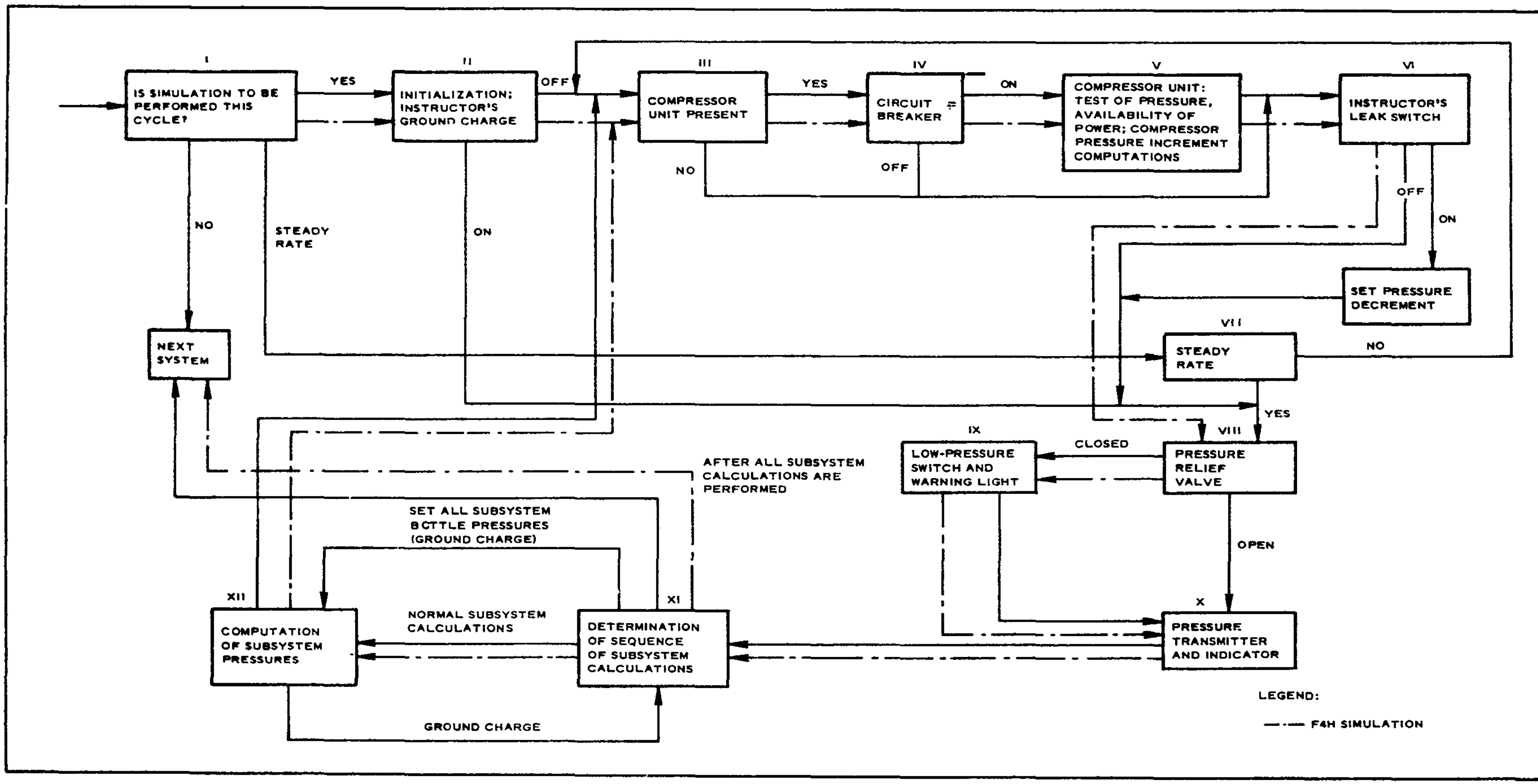

Figure 2 - Basic Diagram of General Pneumatic System Simulation

5. Pressure transmitters located in the main pressure supply lines transmit system pressure to the pilot's indicators.
6. Filters remove foreign matter from the hydraulic fluid.
7. Heat exchangers transfer heat from the hydraulic fluid to engine fuel.
8. Subsystem-actuating cylinders apply hydraulic power to the respective subsystems.
9. Control valves associated with actuators control pressure application to the actuators.
10. Hydraulic fluid moves between the various components through interconnecting lines.

The components and functions not common to all aircraft are:

1. Fluid shutoff valves allow the pilot to stop fluid flow between reservoirs and pumps for controlling a fire.
2. Replenishing systems are used to replace lost fluid. These systems consist of a fluid storage tank, lines, connectors, and a manual pump.
3. A pressure indicating system indicates pressure for each hydraulic pump.
4. A low-pressure warning system is provided for each hydraulic system.
5. Selector switches allow the status (usually pressure) of each hydraulic system to be read on a single indicator.
6. Multiple actuators provide positive control of main control surfaces. That is, more than one hydraulic system is used to power these important control surfaces.
7. Emergency pump operation is sometimes automatically controlled by pressure switches; otherwise, it is controlled manually.
8. Both manual and automatic priority valves are used to distribute available pressure to selected actuators.
9. Accumulator pressure gages indicate the amount of stored pressure in each accumulator.
10. Assorted subsystems that require hydraulic and electrical power are provided to operate the various hydraulic systems.

11. Circuit breakers are sometimes used in the main electric circuits of the hydraulic system.
12. Pressure regulators and reducers control the amount of pressure to particular actuators.
13. Fluid quantity gages provide fluid quantity indications.

The principal subsystems that require hydraulic pressure for operation are:

1. Wing flaps
2. All control surfaces
   a. Ailerons
   b. Rudders
   c. Elevators
   d. Spoilers
   e. Elevons
   f. Stabilizer
   g. Stabilator, etc.
3. Mine door
4. Hydroflaps
5. Speed brakes
6. Landing gear
7. Wheel brakes
8. Rudder feel
9. Tail skid
10. Air compressor
11. Arresting hook
12. Wing fold
13. Wing slats
14. In-flight refueling probe
15. Fuel pumps

The general hydraulic system simulation performs all the calculations involved in describing the above component functions except those for filters and the heat exchanger.

The similarities between the general pneumatic and hydraulic systems permit the hydraulic system to be simulated by extending the methods used for the pneumatic system simulation. The simulation is performed as a subroutine that can be repeated once for each hydraulic system, with appropriate inputs. Within the subroutine, there are several smaller subroutines or loops. The first such loop is concerned with pump simulation and this

loop, or minor subroutine, is used once for each pump of a particular system. The second loop, within the first, simulates the accumulators associated with a particular pump. The third loop, within the second, simulates the loads corresponding to a particular accumulator.

The instructor will have indicators similar to the pilot's, with additional ones to show what operations he and the pilot have made. The instructor will be able to modify the simulation by:

1. A switch to fail the pump pressure indicator
2. A switch that will insert a volume decrement or leak into any hydraulic system.
3. A switch to fail each system pressure indicator
4. Switches to fail the pilot's circuit breakers
5. Switches to fail any or all hydraulic systems

The complete simulation flow chart (see Figure 3) for the general hydraulic system is divided into 18 subroutines, some of which are individually subdivided in the flow chart for illustrative purposes. In such cases the subdivisions are labeled with the subroutine number folowed by small letter; e.g., III, IIIa, IIIb, etc. A complete description of each subroutine is given in Appendix C. Normal hydraulic system simulation for the A4D is indicated in the basic flow chart by a dotted line; steady-rate simulation for the F4H is indicated by a dashed line.

D. Engine Control System.

In developing the method of simulation discussed herein, emphasis was placed upon flexibility with regard to simulating the various kinds of engine control systems, as well as to the type of malfunction that can be introduced in these control systems by the instructor. Unfortunately, achieving greater system flexibility also introduces greater system complexity. However, reasonably accurate and complete routines have been established for the following engine systems and conditions:

1. Engine clearing procedures
2. Air starts
3. Ground starts
4. Starter system
5. Engine ignition system
6. Conditions for engine relight

7. Computation of oil system pressure
8. Computation of externally applied rotor torque
9. Conditions for fuel to be supplied to engine and afterburner fuel pumps
10. Computation of fuel pressure
11. Emergency afterburner modulation system
12. Computation of engine fuel control fuel limits
13. Normal or emergency fuel control operation
14. Computation of fuel demand, fuel available, and fuel supplied to main engine
15. Speed governor operation
16. Conditions for compressor stall and engine flameout
17. Computation of fuel demand, fuel available, and fuel supplied to afterburner
18. Conditions for afterbuenre light-off and blowout
19. Computation of jet nozzle area
20. Turbine exhaust-gas-temperature control system
21. Inlet guide vane and variable stator blade control systems
22. Compressor air-bleed control

The overall engine systems simulation is subdivided into the 13 routines depicted in Figure 4. It is essential that the routines be arranged in the manner indicated since information generated in one routine must be established before the subsequent routines can be properly completed.

Basically, these 13 routines establish all the independent engine parameters: main fuel flow, afterburner fuel flow, nozzle area, compressor bleed valves opened or closed, inlet guide vane and stator blade position, and external rotor torque. These routines also indicate when the various engine operating conditions have been satisfied: compressor stall, main engine flameout and relight, and afterburner light-off and blowout. Thus, the engine simulation is essentially reduced to simulating the thermodynamic relationships between the dependent engine parameters; that is, temperatures, pressures, air flow, gross thrust, and rpm. The engine systems simulation requires only the following dependent variable inputs from the engine simulation: compressor-inlet temperature, compressor-inlet total pressure, compressor-discharge total pressure, compressor-discharge static pressure, turbine exhaust-gas temperature, and engine rpm.

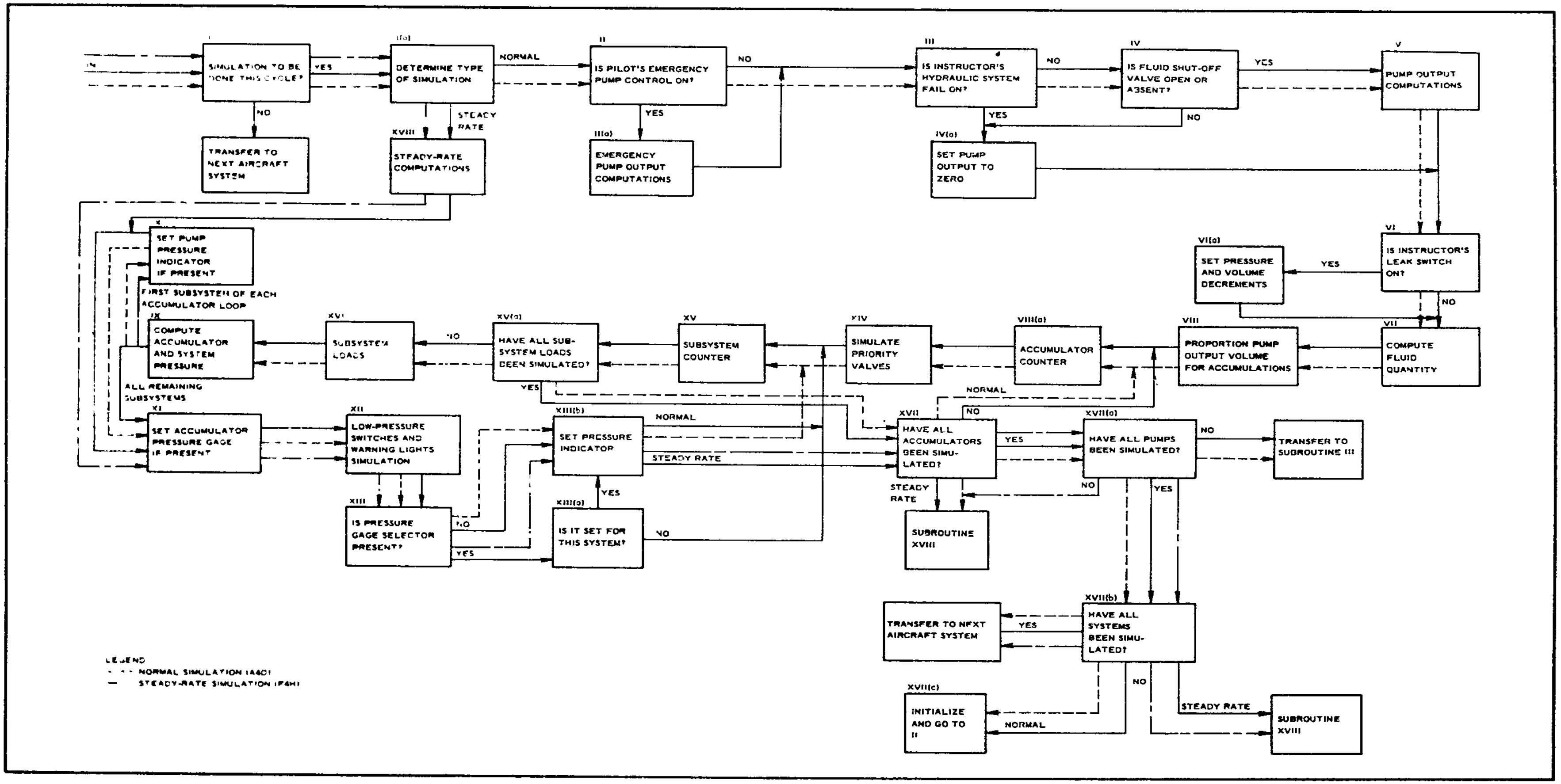

Figure 3 – Basic Diagram of General Hydraulic System Simulation

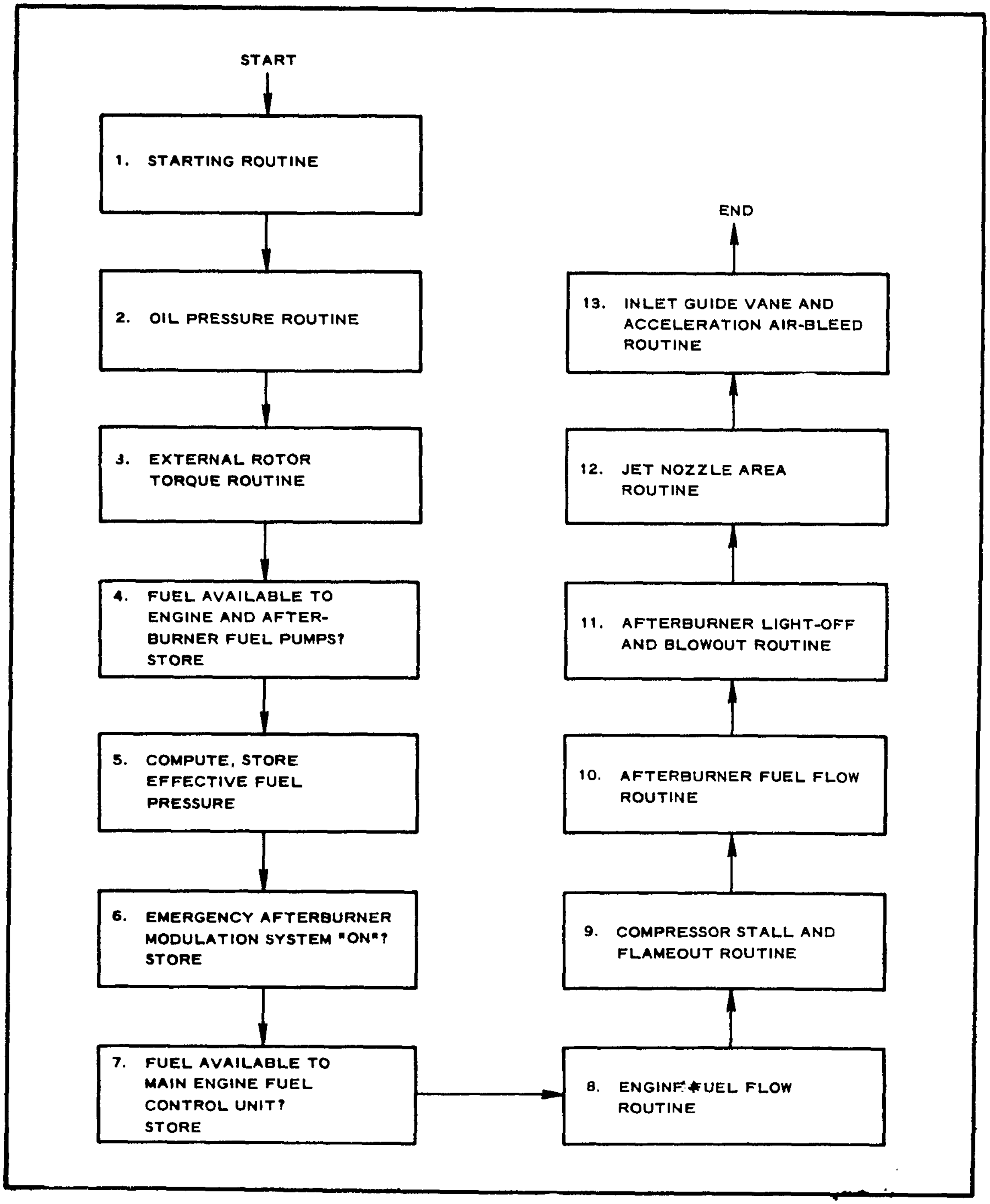

Figure 4 - Basic Diagram of Engine Control System Simulation

The engine control system simulation incorporates considerable latitude in instructor inputs and failures. The basic flow chart in Figure 4 does not include the specific inputs because the list is too extensive. The following list of inputs details the instructor's inputs to the simulation.

1. Ignition system failure
2. Oil system malfunction, partial pressure loss
3. Oil system malfunction, full pressure loss
4. Emergency afterburner system failed by instructor
5. Failure of afterburner fuel pump
6. Failure of engine no. 1 fuel pump
7. Failure of engine no. 2 fuel pump
8. Emergency fuel control system failure
9. Speed governor failed
10. Malfunction of engine control unit
11. Broken throttle linkage
12. Failure of engine fuel pump
13. Rich-lean flameout
14. Afterburner ignitor failed by instructor
15. Acceleration speed switch failed by instructor
16. Temperature override failed by instructor
17. Nozzle actuators failed by instructor

The engine starting routine checks that the engine is properly cleared of excess fuel before it can be started. In addition, the start routine checks all necessary starting parameters such as electric ignition power available, proper rotor speed, and starter operating properly. The oil pressure routine includes, in addition to the normal oil pressure computation, provisions for partial or full pressure loss by the instructor. In conjunction with oil pressure loss, it is possible for the instructor to introduce effects of a binding rotor. The simulation proceeds to establish the amount of rotor torque on the rotor. Next the conditions of fuel availability are resolved and the fuel transfer functions are computed. These transfer functions describe the pressure-delivery rate of the full system for the particular combination of pilot instructor inputs existing at the moment. The total fuel demand situation (both engines and afterburners) is then resolved in the next routines, and the result compared to the preceding fuel-transfer functions to determine the actual flow rate of the system. When the conditions do not conform to the proper limits for the engine, the logic calls for a compressor stall or flameout as determined by Routine 9.

Once the fuel requirements are known, the question of the afterburner flow is adjusted on the basis of the remaining fuel flow available. Routine 11 can then determine whether the afterburner is capable of a light-off or force a blowout. Once the foregoing conditions are known, the nozzle area and inlet guide vane situations can be computed in Routines 12 and 13.

E. Aircraft Fuel System: General Discussion of Fuel Transfer Computations

The general flow chart of the fuel system simulation is shown in Figure 5. One aspect of the airplane fuel system must be considered; it will be handled as part of the initial logic. The airplane fuel system can feed the engines in the normal manner through the service tank booster pumps. However, there are usually alternate modes of supplying fuel, usually for emergency use only. For example; the output manifolds of tank 1 in Figure 5 are labeled P and G for "pressure" and "gravity transfer." The fuel bypass feeds directly from tanks 7, 8, 9, 10, and 11 to the engine fuel system. The logic necessary to establish the state of lines B, P, and G. is not difficult. However, complications arise when the negative g feature is included. Because of these complications, it is desirable to consider the negative g feature as a separate tank with a special subroutine for the computations. Since the negative g feature draws its fuel from the tank in which it is installed, the program will be arranged to consider this as a separate tank. The input fuel will be subtracted from the patron tank volume when g becomes positive.

Blocks A and B are initializing logic and are discussed in Appendix E, item B. Combining the current input data with the initial logic will produce a set of manifold control words that guide the succeeding computation in an efficient manner. In addition to the conditions determined by the initial logic, there are certain system situations that require consideration before actual computation can be started. These considerations are the negative g situation, mentioned above, the fuel vent and jettison subroutines, and the refueling operation. Blocks E, F, G, H, I, J, and K are provided for these special situations.

After these situations are computed, it is necessary to determine the precise amount of fuel demand on the system. Blocks L and M compute the present fuel demand on the airplane fuel system. The lift between tanks must be computed and combined with incremental pressure differences to adjust the line transfer functions for

this iteration. Block O computes the required lifts. The fuel transfer functions for each line are stored in memory and at this point, the program combines the transfer functions for all lines, adjusts them for the dynamic situation of the aircraft, and forms a manifold transfer function. This function is used to determine the manifold output pressure and fuel rate. Once these factors are established, the program returns to the line transfer function and determines the amounts of flow that each line is contributing. This is done for all combinations of cases where the receiving tank may be full, empty, partly full, increasing in volume, or decreasing in volume. This process is repeated for all manifolds and hence the rates for all active lines are determined. It is then possible to sum input and output rates for each tank and determine the new tank volumes for this iteration. It should be noted that through the use of the manifold control word, only active lines were computed, thereby saving much useless computing time. Once the new tank volumes are known, the system is sufficiently determined to read out new data to the pilot's instruments and the other sections of the computer that require the information.

The difficulty in manipulating involved equations, when adjusting to changing dynamic situations, has been circumvented by the transfer function method suggested in this approach. There is also the additional advantage of being able to simulate a large variety of transfer functions with the same approach.

The instructor's inputs to the program, included as shown in Figure 5, will generally be reflected as changes in the input switching data. However, additional input latitude is available by operating on the fuel program readouts. By blocking a readout, instrument failures can be simulated. The specific instructor input failures must be specified for each individual aircraft. A possible list of fuel system failures suitable to the F4H aircraft might be as follows:

1. Left-wing tank transfer valve failure
2. Right-wing tank transfer valve failure
3. Center external tank transfer valve failure
4. Right-wing external tank transfer valve failure
5. Left-wing external tank transfer valve failure
6. Failure of fuselage tank air pressure regulator
7. Failure of wing tank air pressure regulator
8. Failure of engine boost pumps, right pump
9. Failure of engine boost pumps, left pump high-speed mode
10. Open leak lines at various manifolds

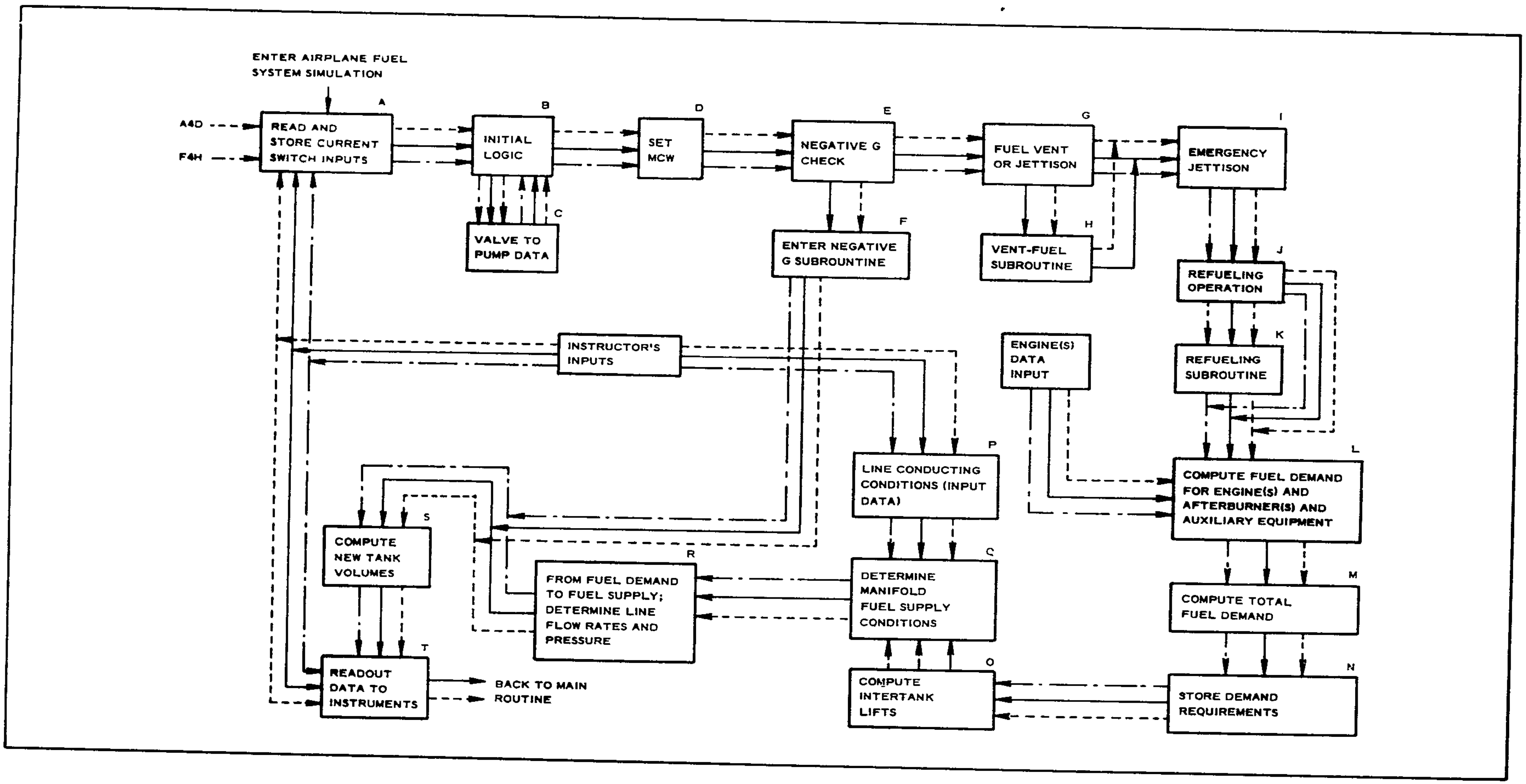

Figure 5 - Basic Diagram of General Fuel System

In addition to these direct failures, there are many side effects from failures in other systems. For example, hydraulic power failure will stop hydraulic fuel pumps.

The aircraft fuel system is concerned with the storage of fuel and its transfer to the engine fuel system; as the fuel complement changes during flight, the aircraft changes its flying characteristics. Rotational inertia, center of gravity, and other factors depend to a large extent on the status of the fuel system. The pilot has various indicators that read out the status of the fuel system during flight.

The aircraft fuel simulation will furnish realistic output data in compliance with input pilot (and instructor) decisions. The fuel simulation is set up by the programmer with the aid of a detailed assembly program. When the fuel system is computed, the state of the entire system is known. The basic approach to computation is as follows:

1. The state of the system is determined by the initializing logic and remains constant for the rest of the computation.

2. Once the state of the system is fixed, the program establishes a system of control words, which allow the computer to bypass inactive segments of the simulation as it proceeds with the computations.

3. The ability of the active portion of the system to transfer fuel is then determined. This process uses a system of fuel transfer functions for transmission of fuel between the various system components.

4. After the system's ability to transfer fuel is known, the demand of all consuming devices is computed. The effect of this demand on the fuel system is then determined.

5. Final system status is computed and volumes, rates, and pressures are read out to the proper destinations.

Pilot switching inputs considered by the simulation are as follows:

1. Fuel transfer
2. Tank selector
3. Fuel dump
4. Emergency jettison
5. Cross-feed
6. Engine prime
7. Bypass

Instructor inputs to the simulation are:

1. Leaks
2. Component failures
   a. Transfer pump failure
   b. Booster pump failure
   c. Hydraulic power not available

In addition to the normal effects of pilot switching decisions, the simulation considers the following special effects:

1. Negative g attitude
2. Fuel vent
3. Tank jettison
4. Emergency stores jettison
5. Refueling operation

Aircraft system failures also affect the fuel simulation. Some of the more important of these are:

1. Valve power not available
2. Ram air insufficient for tank pressurization
3. Compressor bleed air not available
4. Hydraulic power not available

The general flow chart of the fuel system is shown in Figure 5. A detailed explanation of the general flow chart is given in Appendix E. The dotted lines show the computational flow path for the A4D aircraft; the dashed lines show the flow path for the F4H aircraft.

F. Landing Gear System.

The function of the landing-gear system is to retract and extend an aircraft's landing gear. There is also an emergency method for extending the landing gear.

The landing gear consists of the wheels, struts, and other supporting members between the wheels and fuselage. Associated with the landing-gear system are fuselage doors and internal mechanisms that can be operated as a function of the electrical, hydraulic, or pneumatic systems, or can be mechanically actuated by hand.

The following characteristics were found to be common to all landing-gear systems studied, and are therefore assumed to be applicable in the generalized simulation of a landing-gear system.

1. There are three landing gear: the nose gear, left main gear, and right main gear.
2. The landing gear can be extended normally.
3. The landing gear can be retracted normally.
4. The landing gear can be extended by the emergency system.
5. The hydraulic system is used for all landing-gear retractions.
6. A ground safety switch prevents accidental retraction of the landing gear while the aircraft is on the ground.
7. An indicator associated with each gear indicates that the gear is "up and locked," "down and locked," or "unsafe" (in transit).
8. A warning light comes on if all gear are not "up and locked" or all gear are not "down and locked".
9. The indicators and warning light are powered by the electrical system.
10. An electrical system failure will cause the indicators to show an "unsafe" condition.
11. An air-speed limit is imposed on all emergency extensions.
12. The normal hydraulic system is used for normal extension of the landing gear.

The landing-gear systems of some aircraft had additional features that were not common to all landing-gear systems. These additional features will be included in the complete general simulation; those parts of the complete simulation that would not be required for the simulation of a particular aircraft would be eliminated from its program. These additional features included the following.

1. The electrical system is required for normal landing gear operation.
2. Emergency retraction in the air is possible.
3. Emergency retraction on the ground is possible.
4. A test of the emergency extension system can be made while the aircraft is airborne.
5. There may be a circuit breaker in the landing-gear electrical system that can be reset during flight.
6. The warning lamp may come on if the control lever is not at the same position as the landing gear, or if the throttle and attitude are in a landing configuration and the gear is not lowered.
7. The warning light may flash if the flap positions are not consistent with the landing-gear position.

The physical components of the aircraft landing-gear system to be simulated are the landing gear themselves and the pilot's controls for operating the system. In addition, the simulation must provide for a variety of instructor-inserted failures. Internal items such as valves, relays, latches, and reservoirs will not be simulated in detail.

The landing-gear system simulation will use various inputs from the other systems such as air speed, altitude, and attitude, as well as electrical, hydraulic, and pneumatic power. Outputs from the landing-gear system will be provided to the power systems in the form of loads imposed by landing-gear operation. The effect of landing-gear drag will be fed, as an output, to the aerodynamic system of equations.

The following controls or inputs are generally available to the pilot to effect a normal or emergency extension or retraction of the landing gear.

1. The normal control lever can be moved up or down.
2. The ground safety switch can be released.
3. There may be a circuit breaker that can be reset or opened.
4. There is an emergency extension control or procedure, or both.
5. There may be an emergency retraction control or procedure, or both.

Any of the following may serve as outputs from the landing-gear system to the pilot.

1. The normal control lever can be locked.
2. The circuit breaker can be open.
3. The landing-gear warning lamp can light.
4. The landing-gear indicators can show any of three landing-gear positions.
5. The landing gear can extend, as shown by the indicators.
6. The landing gear can retract, as shown by the indicators.
7. The landing gear can fail to operate.
8. The landing gear can be destroyed.
9. The crash system can be energized.

The instructor-induced failures in the landing-gear system are of two types. First, the instructor can fail the normal system, resulting in all gear being locked up or down. In this case, when the pilot follows the emergency-down or emergency-up procedures, the emergency system will respond to call for extension or retraction of the gear.

Second, the instructor can completely fail each separate gear, or gear combination, in its last locked position. In this case, a failure, after insertion by the instructor, must be removed by him before the pilot's remedial action will have any effect. When such a failure has been inserted and removed, an emergency-up or -down command by the pilot will then activate the formerly failed gear.

It is also possible for the instructor to fail each indicator associated with a gear, causing it to remain in the position it was when the failure was inserted. He may also open the circuit

breaker in the landing-gear system, causing a failure similar to a normal system failure, except that it may be possible for the student pilot to close the circuit breaker, thereby retaining normal operation of the landing-gear system. Otherwise, emergency procedures would be necessary.

The results of instructor-induced failures take precedence over the normal operating conditions in the simulation.

The instructor has indicators similar to the pilot's plus indicators for each of the pilot's and instructor's controls.

The basic flow chart for the generalized landing-gear system is shown in Figure 6. A more detailed discussion of the flow chart is given in Appendix F. For a particular aircraft, certain blocks, controls, connections, etc., may be omitted. The dotted line describes an emergency down condition for the A4D; the dashed line describes a normal up condition for the F4H.

G. Electrical System Simulation.

Because of the wide differences in electrical power distribution among the various aircraft, it was decided initially to use some method of selection that would decide on a certain type of electrical system to be considered for simulation. The most logical choice in this regard is a routine that determines the type of generator system and selects that system for simulation.

Generally, the simulation consists of the action a pilot must take as a result of an instructor-inserted failure. The instructor may fail any generator or inverter. The pilot notes these failures through a warning light and takes action that will usually result in the use of emergency power.

It should be noted that there is a certain amount of overlap among the various systems, which could possibly be integrated, but this is not necessary because of the system selection at the beginning of the simulation. As a result, flow charting is somewhat simplified. In pilot action, such as positioning a switch, the end result may be the same but the procedure could be slightly different for a given system. The input can be modified to accomplish the desired result.

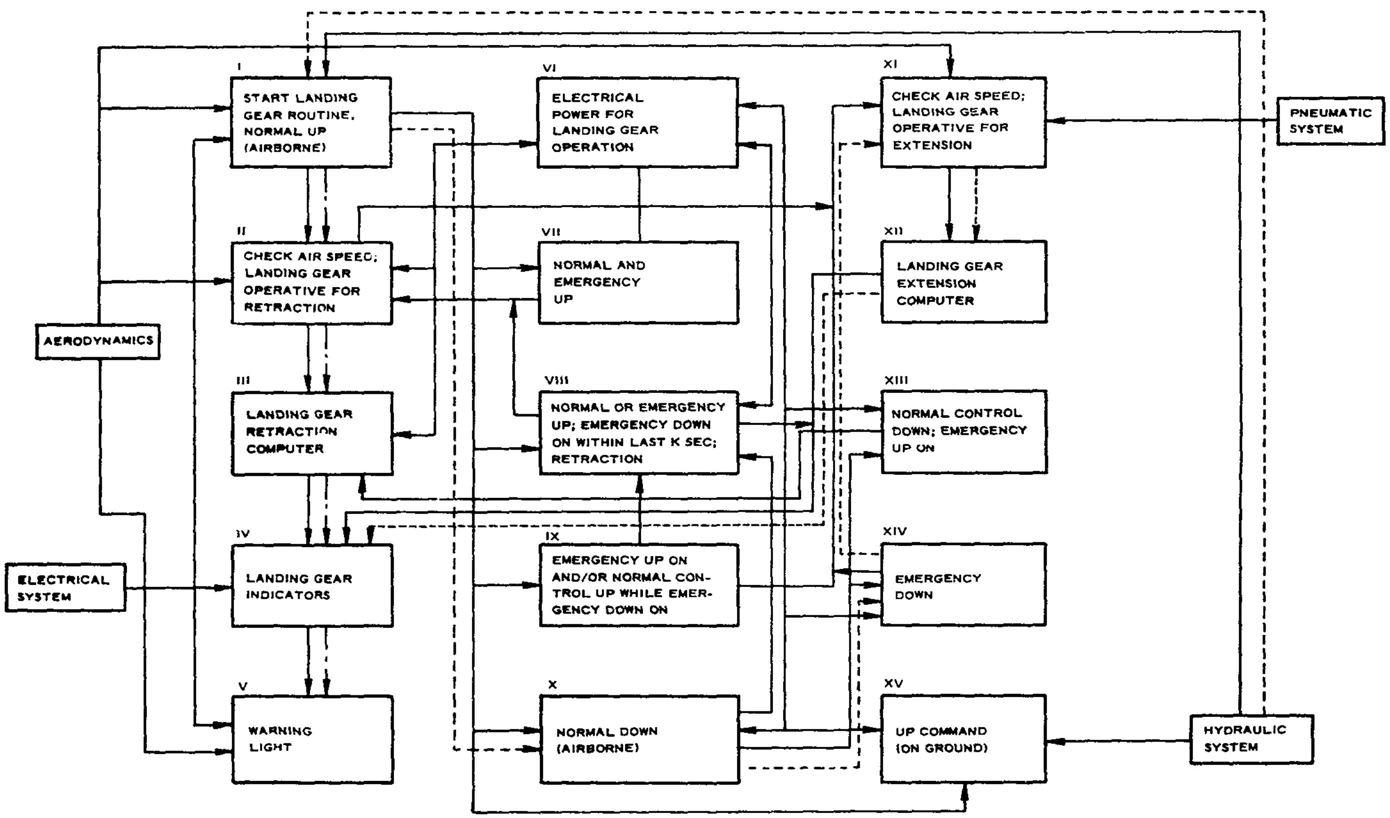

Figure 6 - Basic Diagram for Generalized Landing-Gear System

Not every procedure in the simulation will be pertinent to each aircraft to be simulated. These procedures or branches would be bypassed.

Most of the computations involved are normal and emergency load requirements. It is suggested that maximum loads be considered at all times; that is, assume no failures have occurred in fuses or circuit breakers. Any load computation depends upon the busses that are being supplied for a given condition. The total load is the sum of all the loads on the bus(ses) and can usually be obtained from the flight handbook of the aircraft being simulated.

1. Instructor Inputs.

The instructor's inputs to the system are in the form of failures to various components. He may insert any of the following conditions:

1. Single d-c generator system
   a. Overvoltage condition of the main generator
   b. Failure to inverter no. 1
   c. Failure to inverter no. 2
   d. Complete failure of the main generator
2. Single a-c generator system
   a. Failure to the main generator
3. A-C and d-c generator system
   a. Failure to the main d-c generator
   b. Failure to the main a-c generator
   c. Failure to both generators
4. Double a-c generator system
   a. Failure to either generator
   b. Failure to both generators

2. Instructor Outputs.

Generally, the instructor's outputs are determined by pilot action as a result of instructor inputs; that is, indicators tell the instructor what the pilot is doing.

3. Pilot Inputs.

The pilot may perform the following functions associated with each instructor input:

1. Single d-c generator system
    a. Turn generator reset switch to RESET
    b. Turn instrument power switch to INVERTER NO. 2 position
    c. Turn instrument power switch to INVERTER NO. 2 position
    d. Turn battery-generator switch to OFF and BATTERY-GENERATOR
2. Single a-c generator system
    a. Release the emergency generator
3. A-C and d-c generator system
    a. Set a-c power switch to GENERATOR position
    b. Set a-c power switch to INVERTER position
    c. Set a-c power switch to INVERTER position
4. Double a-c generator system
    a. Set generator switch to RESET and ON
    b. Release emergency generator

In certain cases, the pilot can also:

1. Turn off nonessential equipment
2. Set conditions to maintain control of the aircraft
3. Adjust engine speeds
4. Turn off any generator
5. Retract the emergency generator
6. Select internal or external power for distribution

4. Pilot Outputs.

Outputs to the pilot are in the form of warning lights that may indicate a generator or inverter failure.

The basic flow chart for the A4D and F4H electrical systems is shown in Figure 7; dotted lines are for the A4D, dashed lines for the F4H. The simulation of the electrical system is detailed in Appendix G.

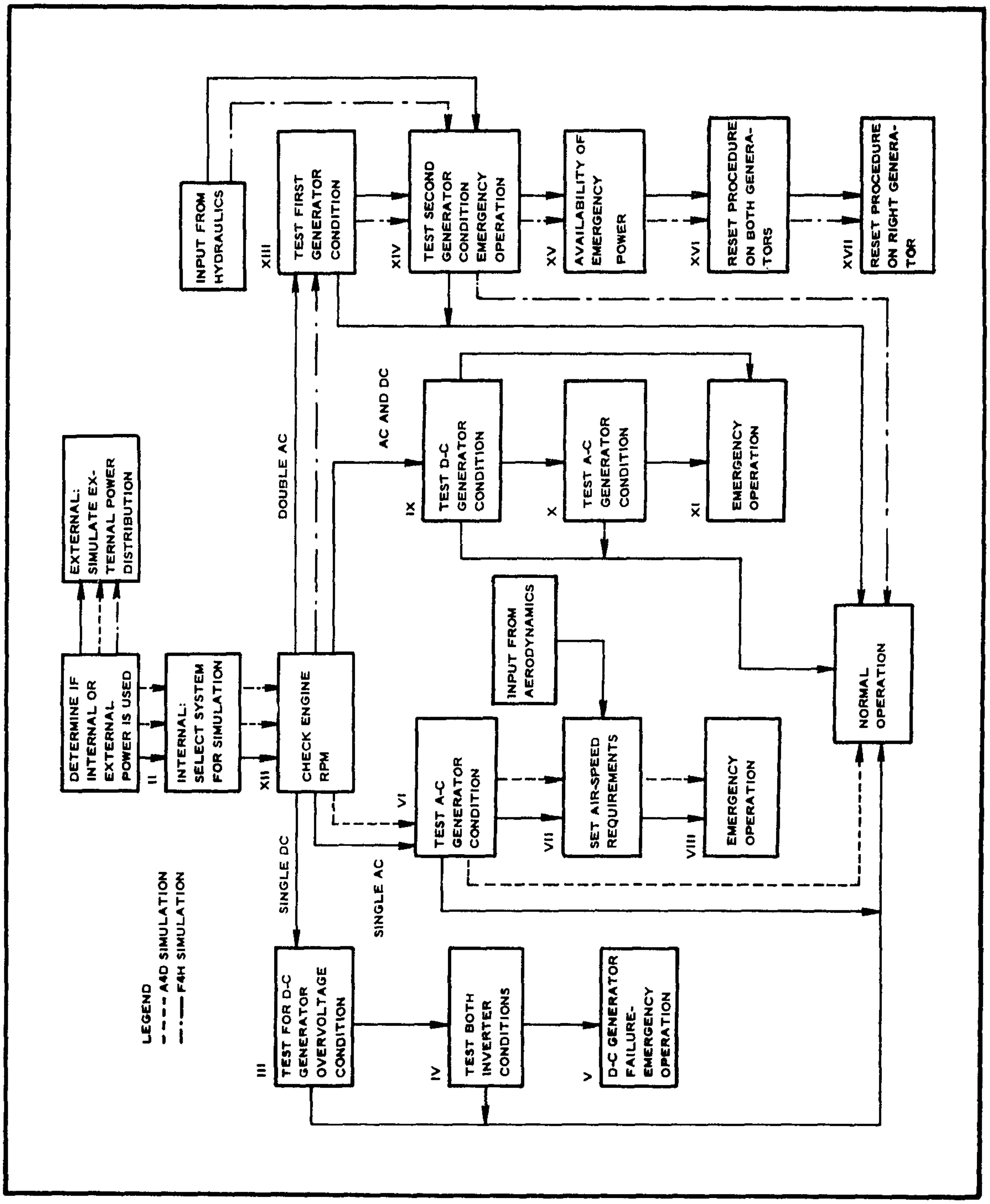

Figure 7 - Basic Diagram of Generalized Electrical System

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SECTION VI. APPENDIX A -- DETAILED SIMULATION FLOW CHART FOR GENERAL FLAPS SYSTEM SIMULATION

A. Definition of Symbols.

The symbols used herein are defined below.

b - A test or comparison computation followed by a branch determined by the computation results

c - A mathematical computation or function evaluation; c* indicates that the results of a c operation are to be stored; "Set" in a c operation indicates that a number is stored that will produce a desired condition.

d - A decision determined by some value or function with a simulated system

f - A branch fixed for the entire simulation by the particular aircraft (input to assembly program)

P - A decision determined by positioning a pilot-controlled switch

I - A decision determined by positioning an instructor-controlled switch

o - An operational function used for transfers, instruction modification, and indexing

\- A bar over a symbol denotes the opposite of that symbol; $\bar{a}$ is read "not a"

h - Electrical or mechanical operations performed by the final hardware; they are not digitally simulated and are always connected to other operations in the flow chart by dashed lines

s - A store operation

The symbol ---◯ denotes pilot outputs in the simulation.

B. Subroutine I.

The flaps system simulation always begins with Subroutine I. It determines whether the simulation is to be done during the i^{th} computation cycle and, if so, whether or not a "steady-rate" computation will suffice. Subroutine I is diagrammed in Figure A-1 and the operations are defined below.

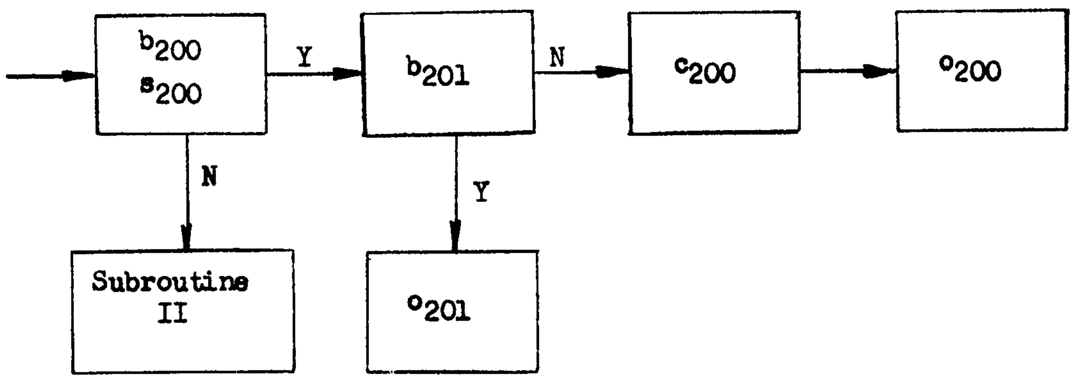

Figure A-1 - Subroutine I for Flap System Simulation

b_{200} - Is "steady-rate" to be simulated? Or does $W_{F_i} - W_{F_{i-1}} = 0$? W_{F_i} is the flaps system simulation first control word for the i^{th} cycle. This control word is composed of digits X_1, X_2, X_3, ... X_n, where n is the total number of "P," "I," and "d" decisions within the main routine. There is a digit of the control word that corresponds to each input to a decision of the above type. This digit is either 0 or 1, depending on whether the corresponding decision should be "no" or "yes". If a switch corresponding to a "P" or "I" decision is not present in a particular aircraft, the associated digit must be zero.

The inputs from other system simulations that form the proper "d" decisions do so by modifying the appropriate digits of the control word. In the case of "P" and "I"

decisions, the switch inputs are converted to the appropriate digital impulse that determines the proper control word digits.

By using such a control word, which may actually be several computer words, and by having a digital simulation computer capable of branching on any of the control word digits, the simulation logic can be greatly facilitated.

The following list defines the proper association between control digits and decisions in the flap system simulation.

Digit	Decision identification	Subroutine in which defined
X_1	I_{200}	II
X_2	P_{200}	III
X_3	I_{201}	IV
X_4	I_{202}	V
X_5	P_{201}	V
X_6	d_{200}	V
X_7	d_{201}	VI
X_8	d_{202}	VI
X_9	P_{202}	VIII
X_{10}	P_{203}	VIII
X_{11}	P_{204}	X
X_{12}	I_{203}	XI
X_{13}	d_{205}	XI
X_{14}	d_{206}	XI
X_{15}	d_{204}	XIV

s_{200} - Store W_{F_i} as next $W_{F_{i-1}}$.

b_{201} - Has "steady-state" been reached? That is, is $(F_p)_{i-1} - (F_p)_{i-2} = 0$? $(F_p)_{i-1}$ is the flap position at the end of the $(i-1)^{th}$ cycle.

o_{201} - Transfer to next system.

c_{200} - Initialization; reset digits of control word associated with c_{217}, c_{218}, c_{219}, c_{220}, c_{223}, c_{224} to zero.

o_{200} - Transfer to Subroutine VIII for "steady-rate" computation.

C. Subroutine II.

Subroutine II determines whether the instructor's flaps freeze switch is on. The Subroutine is shown in Figure A-2, and the operations are defined below.

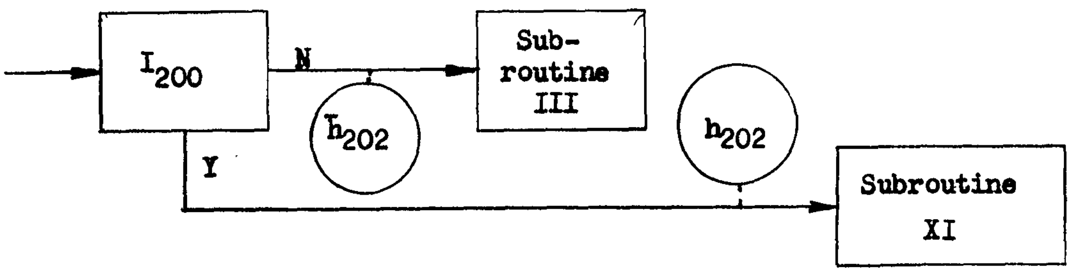

Figure A-2 - Subroutine II for Flap System Simulation

I_{200} - Is instructor's flaps freeze switch on? (test X_1).
$\bar{h}_{202}$ - Turn off instructor's flaps freeze indicator.
h_{202} - Turn on instructor's flaps freeze indicator.

D. Subroutine III.

Subroutine III (see Figure A-3) determines the position of the pilot's emergency flaps control. The operations are defined below.

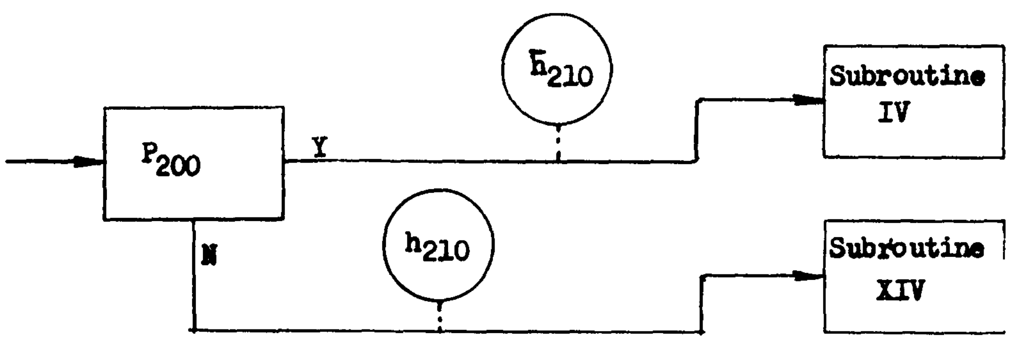

Figure A-3 - Subroutine III for Flap System Simulation

P_{200} - Is pilot's emergency control normal? (test X_2).
h_{210} - Set instructor's indicator associated with P_{200} to ON.
$\bar{h}_{210}$ - Set instructor's indicator associated with P_{200} to OFF.

E. Subroutine IV.

Subroutine IV (see Figure A-4) determines the status of the instructor's normal flaps fail switch. The operations are defined below.

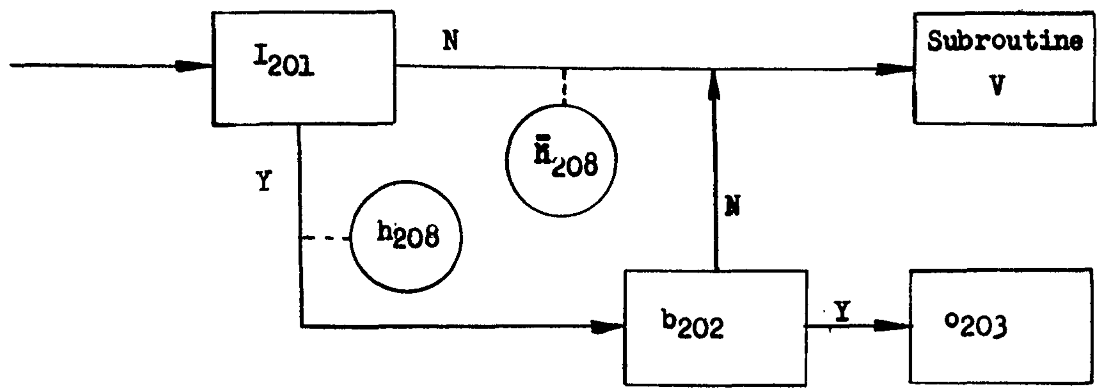

Figure A-4 - Subroutine IV for Flap System Simulation

I_{201} - Is instructor's normal flaps fail switch on? (test X_3).
h_{208} - Turn on instructor's indicator associated with I_{201}.
$\bar{h}_{208}$ - Turn off instructor's indicator associated with I_{201}.
b_{202} - Are flaps full up? Is $(F_p)_{i-1} = 0$?
o_{203} - Transfer to warning device test, Subroutine X.

F. Subroutine V.

Subroutine V determines whether electrical power is needed and available for flaps control. If a circuit breaker is present, it determines the status of the pilot's circuit breaker and the instructor's circuit breaker fail switch. This instructor's circuit breaker fail switch will turn off the pilot's circuit breaker, holding it off until the fail switch is reset. Subroutine V is shown schematically in Figure A-5, and the operations are defined below.

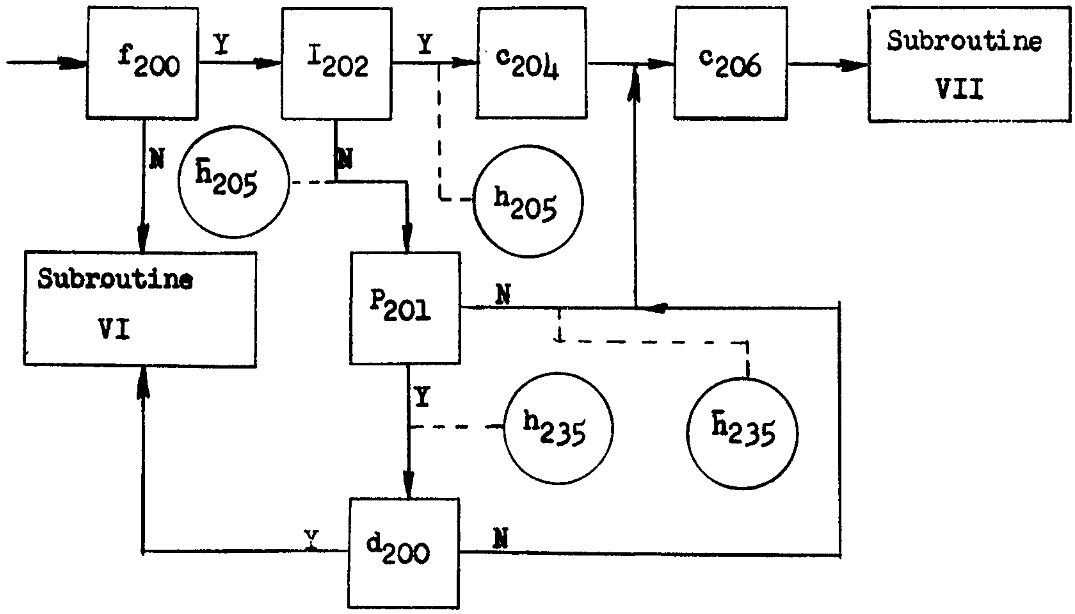

Figure A-5 - Subroutine V for Flap System Simulation

f_{200} - Is a circuit breaker present? (assembly input or test Y_1). Although all f-type branches are indicated as assembly inputs, they can be set by a control word. However, in the absence of an assembly program, the testing and branching involved in the f-type operations must be performed for each complete simulation cycle even though the branches are fixed for the entire simulation. Also, a control word must be prepared manually. Unless the programmer desires to perform a hand assembly, in which case he must proceed on his own, the following method is suggested.

Form a control word (W'_F) similar to the previous one with digits y_1, y_2, ... y_n, each of which corresponds to an f-type branch. This word is loaded into computer storage along with the simulation program. The information needed for the formation of this control word can be found in the aircraft flight handbook. Since a control word digit is either 0 or 1, corresponding to an f branch of "no" or "yes," the following associations can be defined.

Digit	Branch identification	Subroutine in which branch defined
y_1	f_{200}	V
y_2	f_{201}	VI
y_3	f_{202}	IX
y_4	f_{203}	X
y_5	f_{204}	XIV
y_6	f_{205}	XI

I_{202} - Is instructor's circuit breaker fail switch on? (Test X_4).
c_{204} - Set pilot's circuit breaker to OFF.
h_{205} - Set instructor's indicator associated with I_{202} to ON.
h_{205} - Set instructor's indicator associated with I_{202} to OFF.
c_{206} - Close solenoid valve controlling hydraulic pressure to flaps. Set $X_8 = 0$.
P_{201} - Pilot's circuit breaker on? (test X_5).
h_{235} - Set instructor's indicator associated with P_{201} to ON.
d_{200} - 28 vdc available for flaps control? (test X_6).

G. Subroutine VI.

Subroutine VI determines the availability of electrical or hydraulic power to actuate the flaps. Figure A-6 is a schematic of the subroutine, and the operations are defined below.

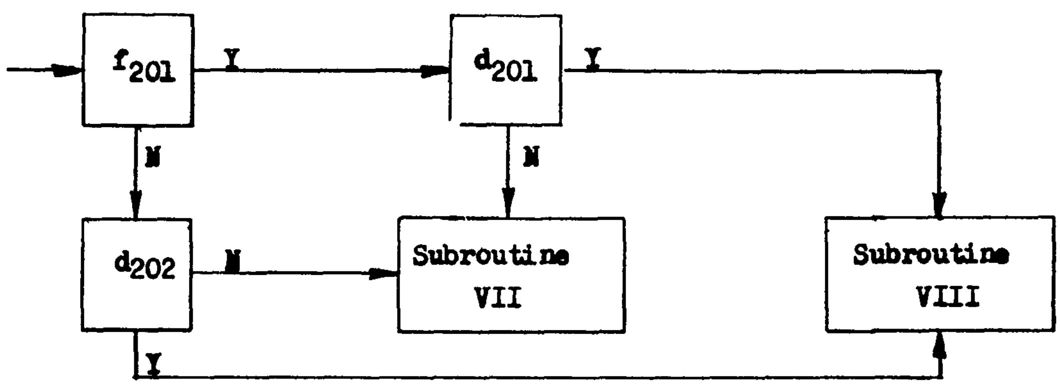

Figure A-6 - Subroutine VI for Flap System Simulation

f_{201} - Is a-c electrical power needed for flap actuation? (assembly input or test y_2).

d_{201} - Is a-c electrical power available for flap actuation? (test X_7).

d_{202} - Is hydraulic pressure available for flap actuation? (test X_8).

H. Subroutine VII.

Subroutine VII (see Figure A-7) determines whether the dynamic pressure is sufficient to move the flaps up when actuating power is lost. The operations are defined below.

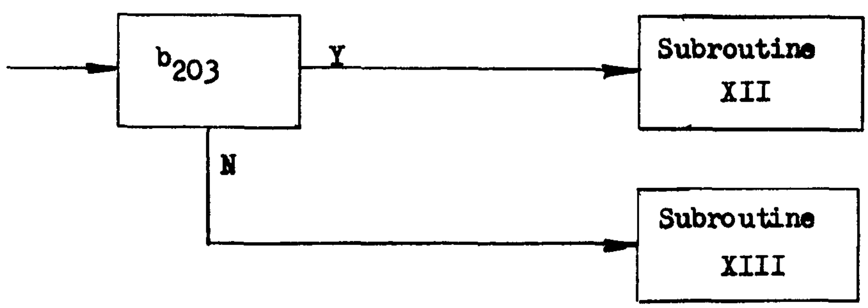

Figure A-7 - Subroutine VII for Flap System Simulation

b_{203} - Is dynamic pressure sufficient to move flaps up after actuating power is lost? Since this condition is somewhat difficult to establish, it is suggested for practical purposes that b_{203} be changed to read: "Is the aircraft airborne?"

I. Subroutine VIII.

Subroutine VIII determines if the flaps are to be moved and how. The subroutine is shown schematically in Figure A-8; the operations are defined below.

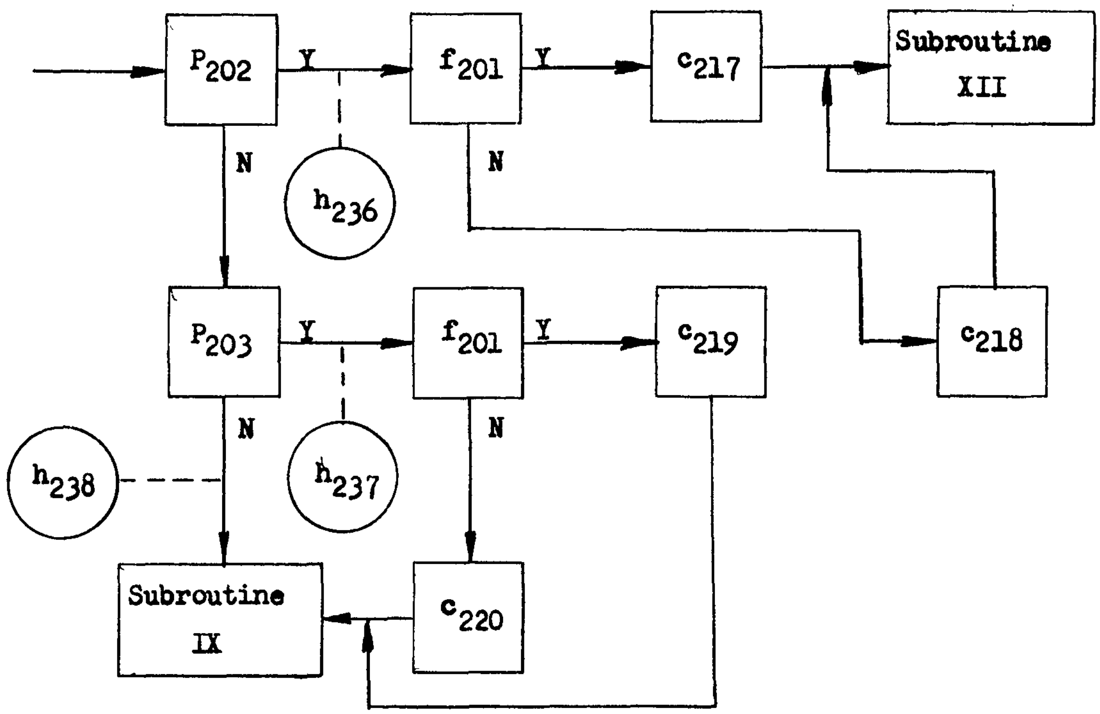

Figure A-8 - Subroutine VIII for Flap System Simulation

p_{202} - Is pilot's flap control up? (test X_9).
p_{203} - Is pilot's flap control down? (test X_{10}).
f_{201} - Is a-c power needed for flap extension? (assembly input or test y_2).
c_{217} - Signal to a-c electrical system for flaps-up power; set proper control word digit to 1.
c_{218} - Signal to hydraulic system for flaps-up power; set proper control word digit to 1.
c_{219} - Signal to a-c electrical system for flaps down; set proper control word digit to 1.
c_{220} - Signal to hydraulic system for flaps down; set proper control word digit to 1.
h_{236} - Set instructor's indicator associated with P_{202} to UP.
h_{237} - Set instructor's indicator associated with P_{203} to $\overline{\text{DOWN}}$.
h_{238} - Set instructor's indicator associated with P_{203} to $\overline{\text{STOP}}$.

J. Subroutine IX.

Subroutine IX determines whether a relief valve or blowback feature is incorporated in the flaps system and, if so, whether air speed is sufficient to move the flaps up against the actuating force. The subroutine is diagrammed in Figure A-9, and the operations are defined below.

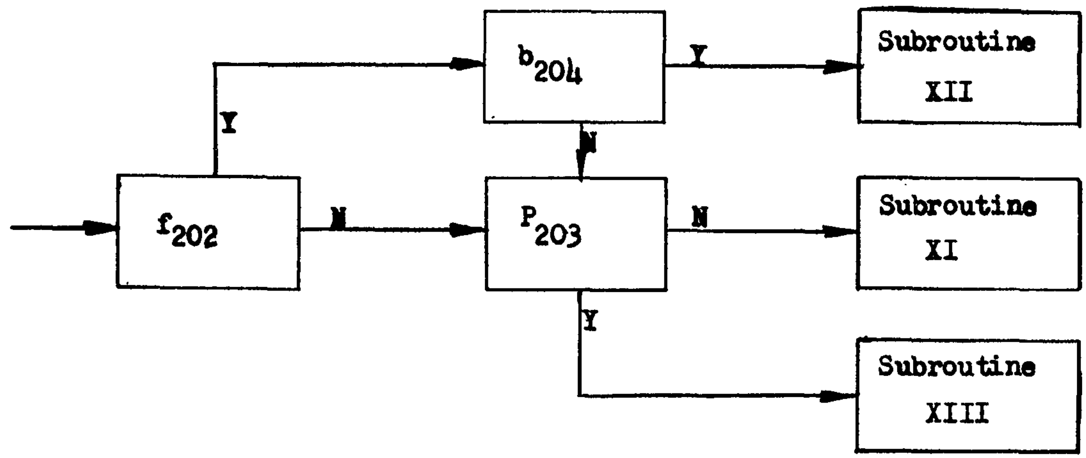

Figure A-9 - Subroutine IX for Flap Simulation System

f_{202} - Is pressure relief or blowback feature present? (assembly input or test y_3).

b_{204} - Is air speed sufficient for blowback? Is $V_a > V_b$? (V_a is air speed and V_b is the speed at which blowback begins.) The data for this subroutine can be obtained directly from the aircraft flight handbook.

K. Subroutine X

Subroutine X establishes the presence or absence of a warning device and determines whether or not it is on. Subroutine X is shown schematically in Figure A-10, and the operations are defined below.

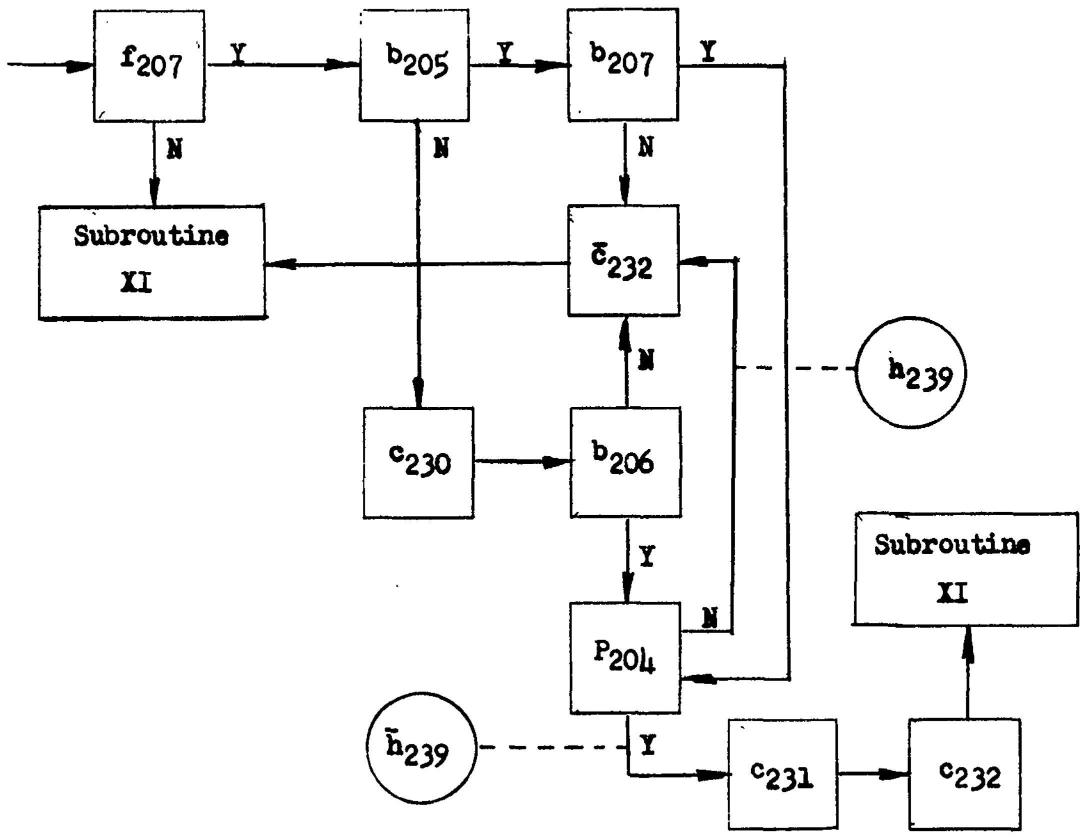

Figure A-10 - Subroutine X for Flap System Simulation

f_{203} - Is a warning device present? (assembly input or test y_4).
b_{205} - Are the flaps up? $(F_p)_{i-1} = 0$?
b_{206} - Warning device sequence check with flaps up, including air-speed test.
b_{207} - Warning device sequence check with flaps down. (These sequence checks are fully described in the aircraft flight handbook. This subroutine was designed for a feature of the P6M.)
P_{204} - Is pilot's warning device circuit breaker on? (test X_{11})
c_{230} - Set special controls.
c_{232} - Turn on warning device.
$\bar{c}_{232}$ - Turn off warning device.
h_{239} - Set instructor's indicator associated with P_{204} to ON.

L. Subroutine XI.

Subroutine XI determines the outputs to the flap position indicator and aerodynamics. Also, the status of the instructor's indicator fail switch is established. The block diagram of the system is shown in Figure A-11, and the operations are defined below.

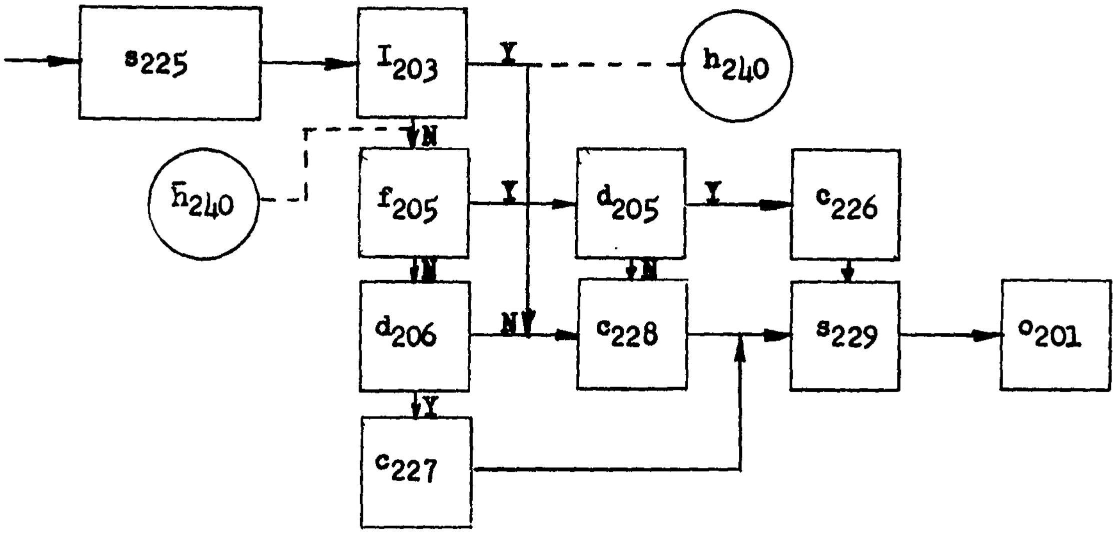

Figure A-11 - Subroutine XI for Flap System Simulation

s_{225} - Store $\frac{(F_p)_i}{F_{max}}$ for output to aerodynamics, where F_{max} is the maximum flap deflection, as obtained from the flight handbook.
I_{203} - Is instructor's indicator fail on?
f_{205} - Is dc needed for indicator? (assembly input or test y_6).
d_{205} - Is dc available? (test X_{13}).
d_{206} - Is ac available? (test X_{14}).
c_{228} - Set indicator is inoperative.
s_{229} - Store $\frac{(F_p)_i}{F_{max}}$ for output to flap position indicator.
o_{201} - Transfer to next system simulation.
h_{240} - Set instructor's indicator associated with I_{203} to ON.

M. Subroutine XII.

Subroutine XII is the flaps-up computation. The rate of change in flap position, ΔU, is an assembly input constant. The flaps full-up position is assumed to represent the reference (zero degrees deflection). The subroutine is shown in Figure A-12; the operations are defined below.

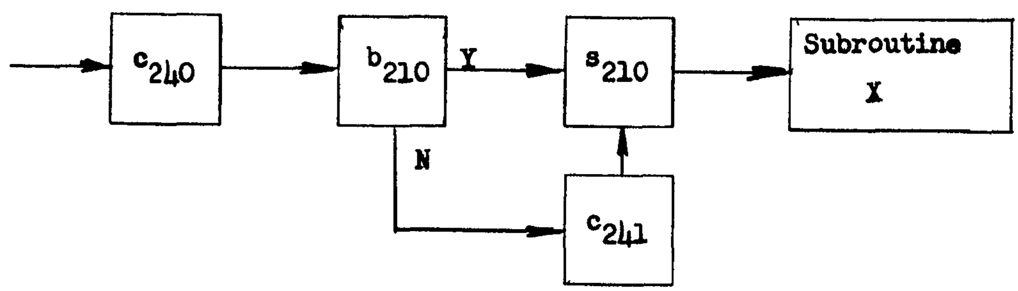

Figure A-12 - Subroutine XII for Flap System Simulation

c_{240} - Form $(F_u)_i = (F_p)_{i-1} - \Delta U(t_s)$, where $(F_u)_i$ is the flap position at the end of the i^{th} computation cycle during the upward movement simulation, $(F_p)_{i-1}$ is the corresponding position at the end of the $(i - 1)^{th}$ cycle, and t_s is the simulation cycle time. ΔU is determined by dividing the full flap deflection in degrees by the total retraction time. Both numbers are usually given in the aircraft flight handbook; otherwise, they can be found in the aircraft trainer systems report.

b_{210} - Is $F_u \geq 0$?

c_{241} - Set $F_u = 0$.

s_{210} - Store $(F_u)_i$ as $(F_p)_{i-1}$.

N. Subroutine XIII.

Subroutine XIII, the flaps-down computation, is similar to the flaps-up computation, except that the constant increment is ΔD. Figure A-13 is the block diagram; the operations are defined below.

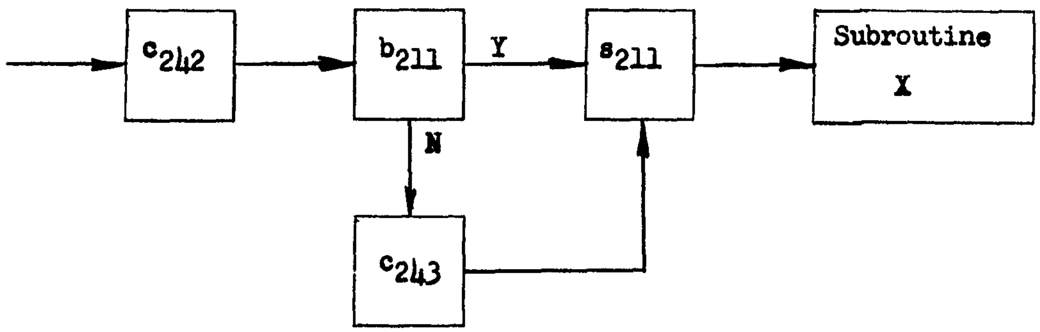

Figure A-13 - Subroutine XIII for Flap System Simulation

c_{242} - Form $(F_d)_i = (F_p)_{i-1} + \Delta D(t_s)$, where $(F_d)_i$ is the flap position at the end of the i^{th} cycle during downward movement simulation, and $(F_p)_{i-1}$ is the corresponding position at the end of the $(i - 1)^{th}$ cycle.

ΔD is determined similarly to ΔU except the total extension time is used instead of total retraction time.

b_{211} - Is $(F_d)_i \leq$ maximum deflection (F_{max})?

c_{243} - Set $(F_d)_i = F_{max}$

s_{211} - Store $(F_d)_i$ as $(F_p)_{i-1}$.

O. Subroutine XIV.

Subroutine XIV establishes the type and availability of power required for the emergency flaps system. The block diagram is shown in Figure A-14; the operations are defined below.

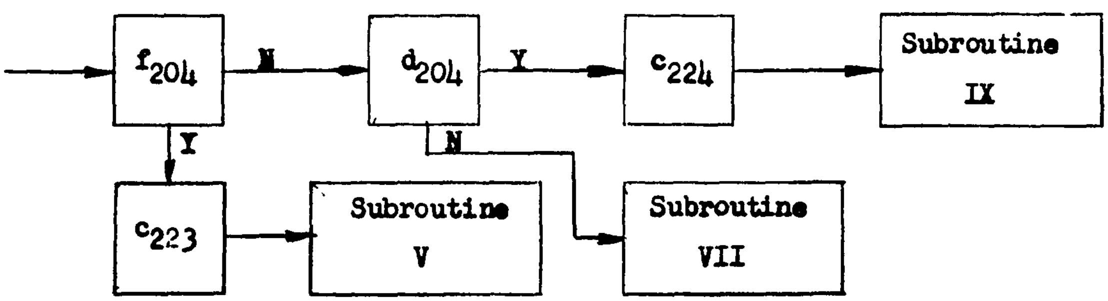

Figure A-14 - Subroutine XIV for Flap System Simulation

f_{204} - Is the emergency system hydraulic? (assembly input or test y_5).
d_{204} - Is pneumatic pressure available? (test X_{15}).
c_{223} - Turn on the emergency hydraulic pump; set control word digit to 1.
c_{224} - Signal to pneumatic system for power; set control word digit to 1.

P. Preparation of Input Data for A4D Flap System Simulation.

The second control word is formed from information obtained from the A4D flight handbook wing-flaps section. The proper digit values are given below.

Digit	Value	Branch identification	Subroutine in which branch defined
y_1	0	f_{200}	V
y_2	0	f_{201}	VI
y_3	1	f_{202}	IX
y_4	0	f_{203}	X
y_5	0	f_{204}	XIV
y_6	1	f_{205}	XI

This list indicates that subroutines V, VI, X, and XIV are not used in simulating the A4D. The value of V_b in Subroutine IX is found from the flight handbook to be 210 knots IAS, and the value of F_{max} in Subroutine XI is found to be 50 degrees. The times for flap retraction and extension are found in the A4D trainer systems report to be 5 and 10 sec, respectively. ΔU is computed to be 50 deg/5 sec, or $\Delta U = 10$ deg per second. Similarly, ΔD is computed to be 50 deg/10 sec, or $\Delta D = 5$ deg per second.

SECTION VII. APPENDIX B - DETAILED SIMULATION FLOW CHART FOR GENERAL PNEUMATIC SYSTEM.

The types of operations represented by the flow-chart symbols are the same as those defined in Appendix A.

A. Subroutine I.

Subroutine I determines whether the high-pressure pneumatic system is to be simulated during the i^{th} cycle and, if so, whether a "steady-rate" simulation will be adequate. The flow chart is given in Figure B-1; operations are defined below.

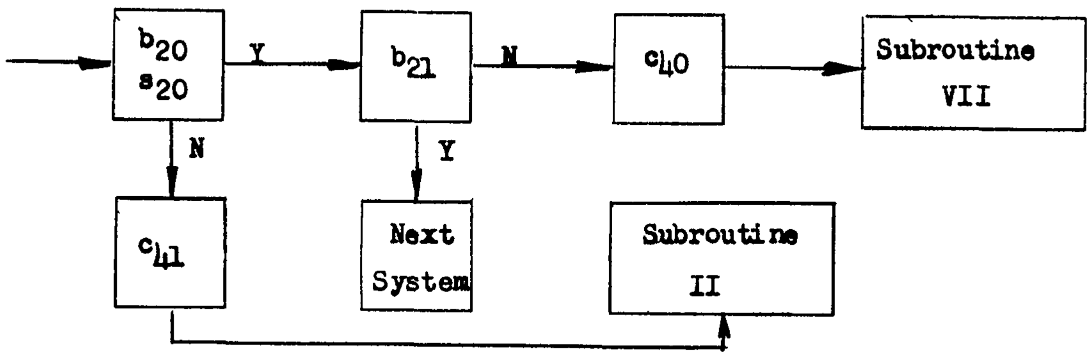

Figure B-1 - Subroutine I for Pneumatic System Simulation

b_{20} - Is "steady-rate" to be simulated? That is, does $W_{pi}-W_{pi-1}=0$? W_{pi}, the first control word of the pneumatic system simulation for the i^{th} simulation cycle, is similar to the flap system simulation first control word. The digits will be denoted by U_1, U_2, ..., and the proper relationships between these digits and the "P," "I," and "d" decisions in the pneumatic system flow chart are as follows.

Digit	Decision identification	Subroutine in which defined
U_1	I_1	II
U_2	I_4	IV
U_3	P_1	IV
U_4	d_2	V
U_5	d_3	V
U_6	d_4	V

Digit	Decision identification	Subroutine in which defined
U_7	d_5	V
U_8	I_3	VI
U_9	d_7	IX
U_{10}	I_2	X
U_{11}	d_8	X
U_{12}	d_9	X
U_{13}	I_1	XI
U_{14}	d_{10}	XII-b
U_{15}	d_{11} (+ subsystem index)	XII-a
U_{16}	d_{11} (+ subsystem index)	XII-a
.	. " "	"
.	. " "	"
.	. " "	"
U_{30}	. " "	"
U_{31}	d_{30}	"
U_{32}	d_{31}	"

s_{20} - Store W_{p_i} as $W_{p_{i-1}}$

b_{21} - "Steady-state" test. Compressor must be absent or not operating and the first control-word digits U_{14} through U_{30} must be zero for a steady-state to exist and a corresponding "Y" branch. Digits U_{14} through U_{30} correspond to the control valve position of subsystems 1 through 17, respectively. U_{14} and U_{15} are illustrated.

c_{40} - Initialization; reset U_{31} to 1. Reset subsystem index.

c_{41} - Set U_{31} to 0.

B. Subroutine II.

The status of instructor's ground charge switch is determined in Subroutine II (see Figure B-2). The operations are defined below.

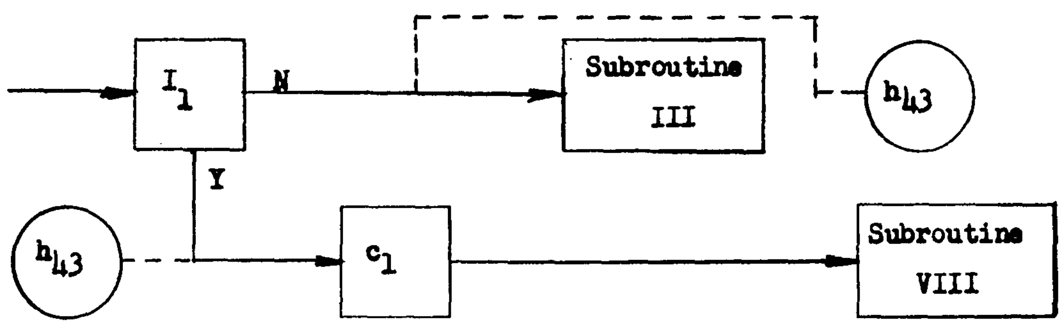

Figure B-2 - Subroutine II for Pneumatic System Simulation

I_1 - Is instructor's ground charge switch on? (test U_1)
h_{43} - Set instructor's ground charge indicator to ON.
h_{43} - Set instructor's ground charge indicator to $\overline{\text{OFF}}$.
c_1 - Set system pressure to normal operating level; that is, to $P_{i,j,k,\ell,m} = P_{pN}$, where $P_{i,j,k,\ell,m}$ is the system pressure associated with the i^{th} computation cycle, the j^{th} pressure storage unit (bottle), the k^{th} compressor cycle, the ℓ^{th} load, and the m^{th} instructor-inserted leak.

C. Subroutine III.

Subroutine III is a branch fixed by an assembly input that establishes the presence of a compressor unit. The flow chart is presented in Figure B-3, and the operations are defined below.

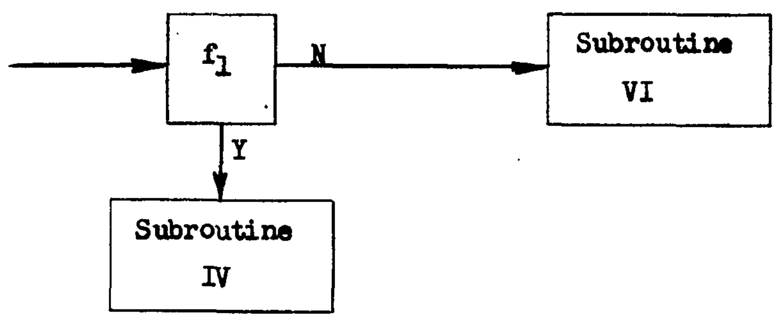

Figure B-3 - Subroutine III for Pneumatic System Simulation

f_1 - Is a compressor unit presented? (test V_1). The pneumatic system simulation second control word is similar to the corresponding control word for the flap system. The association between its digits and f-type branches is given below.

Digit	Branch identification	Subroutine in which defined
V_1	f_1	III
V_2	f_{11}	IV
V_3	f_2	V
V_4	f_3	V
V_5	f_4	V
V_6	f_6	IX
V_7	f_7	X
V_8	f_{10}	XI

D. Subroutine IV.

Subroutine IV determines the status of the pilot's circuit breaker and the instructor's circuit breaker fail switch. This circuit breaker controls electrical power to the compressor unit. This subroutine is diagrammed in Figure 4; the operations are defined below.

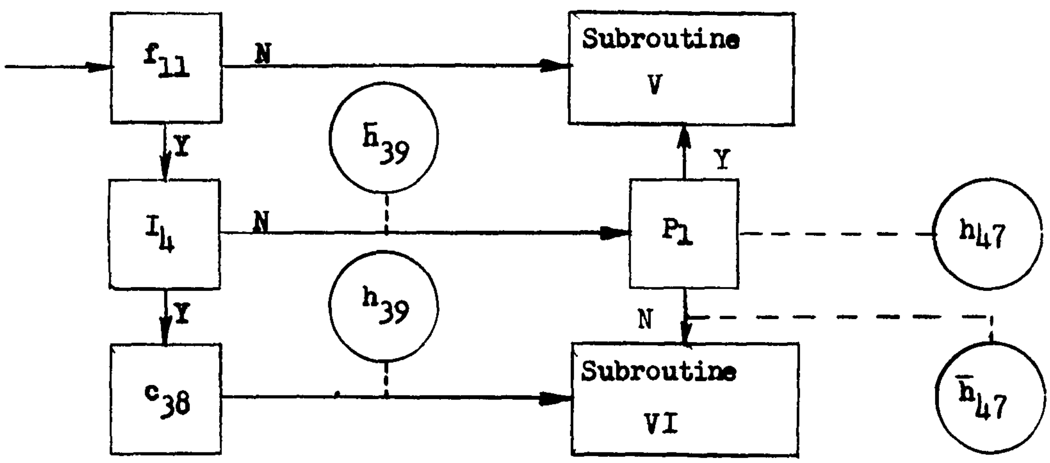

Figure B-4 - Subroutine IV for Pneumatic System Simulation

f_{11} - Is circuit breaker present? (test V_2).
I_4 - Is instructor's circuit breaker fail switch on? (test U_2)
c_{38} - Set pilot's circuit breaker to OFF.
h_{39} - Set instructor's circuit breaker fail indicator to ON.
P_1 - Is pilot's circuit breaker on? (test U_3).
h_{47} - Set instructor's indicator associated with P_1 to ON.

E. Subroutine V.

Subroutine V tests the system pressure to determine whether the compressor is supposed to be simulated and, if so, that it performs the simulation. The flow chart is given in Figure B-5, and the operations are defined below.

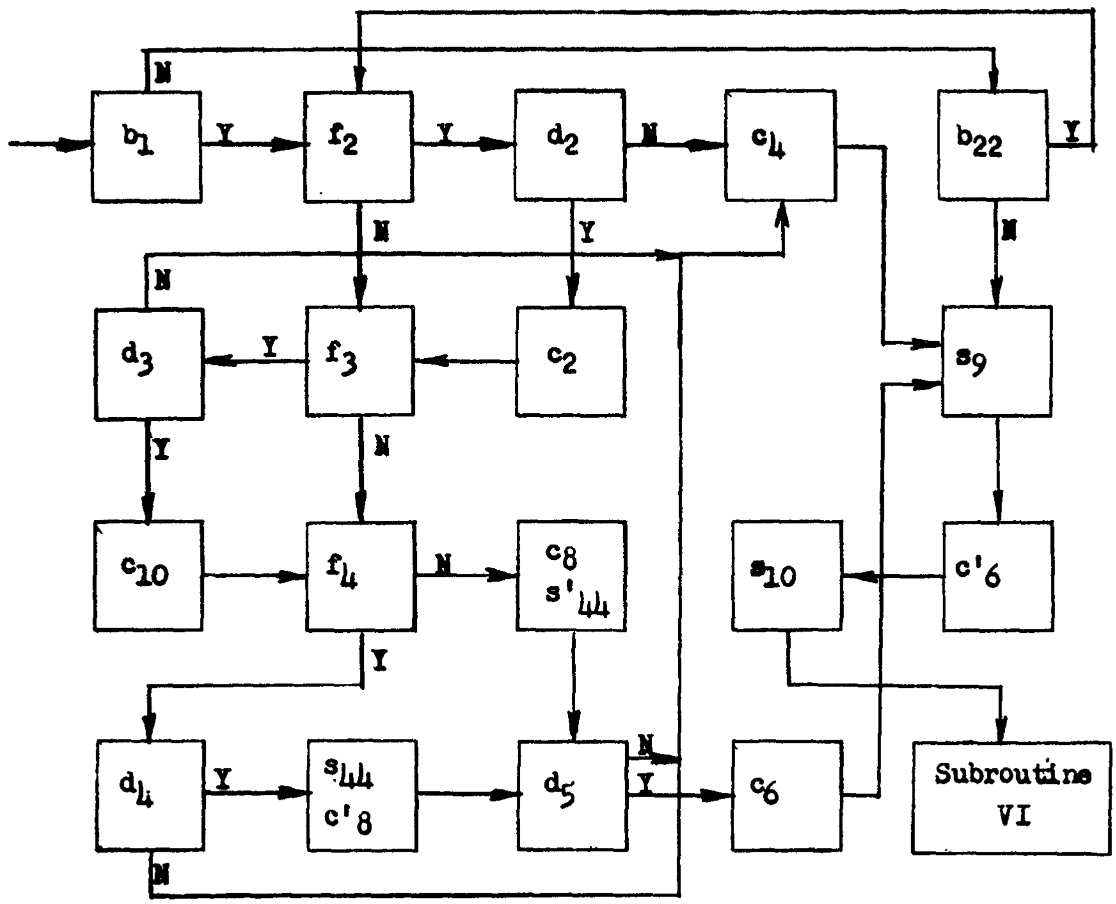

Figure B-5 - Subroutine V for Pneumatic System Simulation

b_1 — Is $P_{i,j,k,l,m} \leq P_{c_{min}}$? $P_{c_{min}}$ is the pressure at which compressor operation begins.

b_{22} - Is $P_{i,j,k,l,m} < P_{c_{max}}$? $P_{c_{max}}$ is the pressure at which the compressor stops. Both $P_{c_{min}}$ and $P_{c_{max}}$ are obtained from the maintenance handbook or simulator systems report.

d_2 - Is dc available? (test U_4).
c_4 - Set compressor mass increment to zero; that is, $\Delta m_{k+1} = 0$.
f_3 - Is a-c electrical power needed for compressor operation? (test V_4).
f_2 - Is d-c electrical power needed for compressor control? (test V_3).
d_3 - Is ac available? (test U_5).
f_4 - Is hydraulic power needed to operate compressor? (test V_5).
d_4 - Is hydraulic power available? (test U_6).
s_{44} - Signal to hydraulic system for power to compressor; that is, set proper control-word digit to 1.
s'_{44} - Signal to hydraulic system for no power to compressor; that is, set proper control-word digit to zero.
d_5 - Input from engine; is bleed air rate all right? (test U_7).
c_6 - Calculation of mass of air increase due to compressor operation. The inlet air supply to the compressor is regulated to a pressure of one standard atmosphere. The volume rate of delivery, $\Delta V_p/\Delta t$, is a constant, C_1, up to an outlet pressure, P_{po}; it then drops off linearly to zero at the normal system pressure, P_{pN}. This may be expressed as

$$\frac{\Delta V_p}{\Delta t} = C_1 , \qquad (0 \leq P_{i,j,k,\ell,m} \leq P_{po}) \qquad \text{(B-1a)}$$

$$\frac{\Delta V_p}{\Delta t} = A_1 + B_1 (P_{i,j,k,\ell,m}), \qquad (P_{po} < P_{i,j,k,\ell,m} \leq P_{pN}) \qquad \text{(B-1b)}$$

and

$$\frac{\Delta V_p}{\Delta t} = 0. \qquad (P_{i,j,k,\ell,m} > P_{pN}) \qquad \text{(B-1c)}$$

Constants C_1, P_{pN}, and P_{po} are found in the aircraft handbook of maintenance instructions for the pneumatic system; they may also sometimes be found in the aircraft trainer systems report. Constants A_1 and B_1 are determined from expressions,

$$\left.\begin{aligned} A_1 &= C_1 \left(1 - \frac{P_{po}}{P_{po} - P_{pN}}\right) \\ B_1 &= \frac{C_1}{P_{po} - P_{pN}} \,. \end{aligned}\right\} \qquad \text{(B-2)}$$

Equations 1a, 1b, and 1c are converted to give the mass of compressor air delivery as follows:

$$\Delta m_{k+1} = C_1 \rho_o \; \Delta t_{k+1}, \qquad (0 \leq P_{i,j,k,\ell,m} \leq P_{po}) \qquad \text{(B-3a)}$$

$$\Delta m_{k+1} = (A_1 + B_1 P_{i,j,k,\ell,m}) \; (\rho_o) \; (\Delta t_{k+1}), \qquad \text{(B-3b)}$$
$$(P_{po} < P_{i,j,k,\ell,m} \leq P_{pN})$$

and

$$\Delta m_{k+1} = 0, \qquad (P_{i,j,k,\ell,m} > P_{pN}) \qquad \text{(B-3c)}$$

where ρ_o is the density of air at one standard atmosphere and Δt_{k+1} is the time elapsed since the k^{th} compressor cycle simulation. This conversion is made so that a fixed system volume of air can be used. The system volume at normal pressure is converted to mass and entered as an input constant into the simulation program. The system volume is arbitrarily taken as twice the largest individual storage bottle volume. These storage bottle volumes (see item 12, below) are usually found in the aircraft flight handbook or the maintenance handbook for the pneumatic system.

c'6 - Calculation of pressure increase due to compressor operation. For a given volume of air at a fixed temperature, the pressure is proportional to the mass; hence, the main system pressure at the end of the $(k+1)^{th}$ compressor cycle is

$$P_{i,j,k+1,\ell,m} = \frac{(P_{i,j,k,\ell,m}) \; (m_{i,j,k,\ell,m} + \Delta m_{k+1})}{m_{i,j,k,\ell,m}},$$

where $m_{i,j,k,\ell,m}$ is the mass of air contained in the main system at the end of the k^{th} compressor cycle, and Δm_{k+1} is the mass of air added to the main system by the $(k+1)^{th}$ compressor cycle.

c_8 - Set signal for electrical power; set proper control-word digit to 1.

s_9 - Store Δm_{k+1} for steady-rate computations.

s_{10} - Store pressure.

c'_8 - Set signal for no electrical power; set proper control-word digit to zero.

F. Subroutine VI.

Subroutine VI determines the position of the instructor's leak switch, providing the corresponding output to the pressure summation point (c_9). The flow chart is shown in Figure B-6, and the operations are defined below.

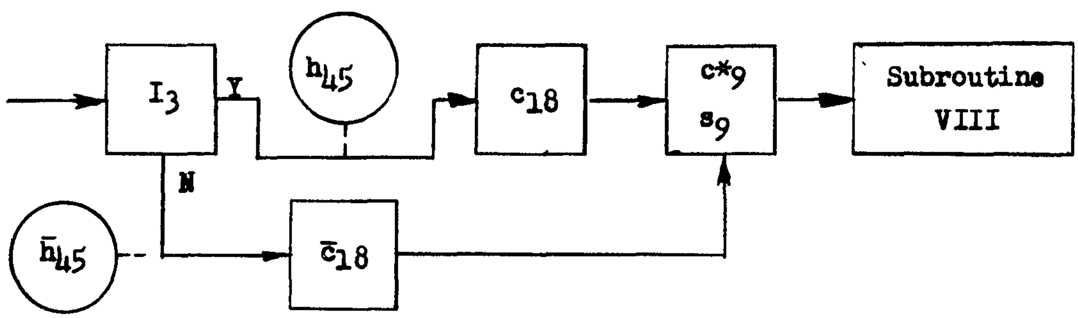

Figure B-6 - Subroutine VI for Pneumatic System Simulation

I_3 - Is instructor's leak switch on? (test U_8).

h_{45} - Set instructor's leak switch indicator to ON.

$\bar{h}_{45}$ - Set instructor's leak switch indicator to $\overline{\text{OFF}}$.

c_{18} - Set pressure decrement, ΔP_{m+1}.

$\bar{c}_{18}$ - Set zero pressure decrement, $\Delta P_{m+1} = 0$.

c^*_9 - Form new pressure, $P_{i,j,k+1,\ell,m+1} = P_{i,j,k+1,\ell,m} - \Delta P_{m+1}$.

G. Subroutine VII

Subroutine VII (see Figure B-7) provides the steady-rate computations for the air compressor simulation. The operations are defined below.

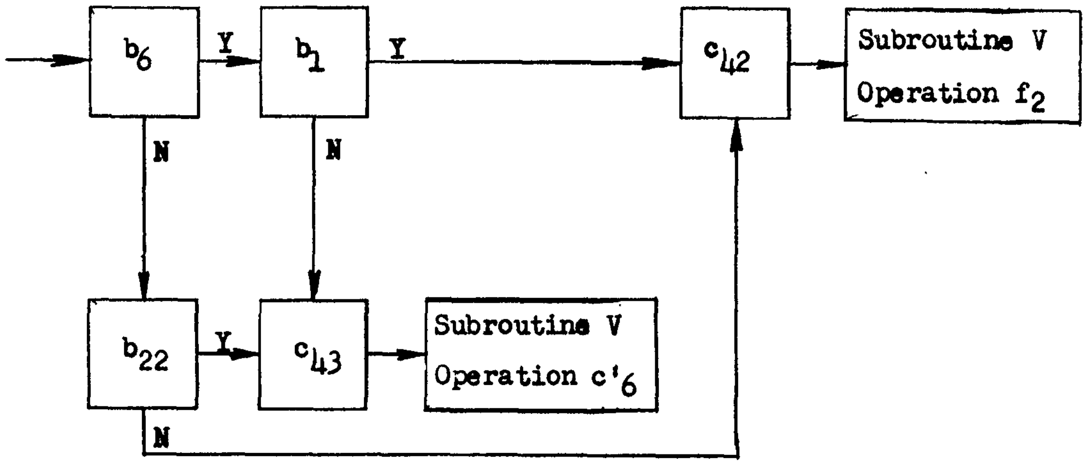

Figure B-7 - Subroutine VII for Pneumatic System Simulation

b_6 - Is $\Delta m_{k+1} = 0$?
c_{42} - Set U_{32} to 0.
c_{43} - Set U_{32} to 1.

H. Subroutine VIII

Subroutine VIII simulates a pressure-relief valve by setting the system pressure equal to the maximum allowable, if the calculated pressure is too great. This subroutine is diagrammed in Figure B-8; the operations are defined below.

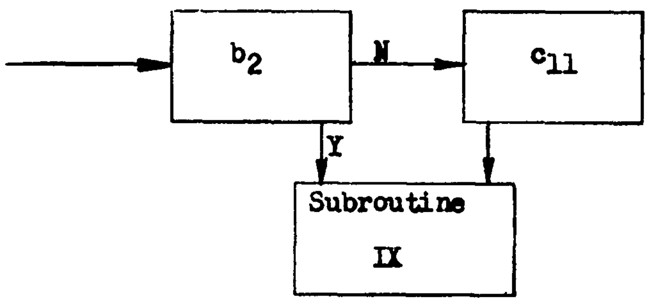

Figure B-8 - Subroutine VIII for Pneumatic System Simulation

b_2 - Is $P_{i,j,k+1,\ell,m+1} \leq P_{p,max}$? The maximum system pressure, $P_{p,max}$, is obtained from the flight handbook.

c_{11} - Set $P_{i,j,k+1,\ell,m+1} = P_{p,max}$.

I. Subroutine IX.

Subroutine IX establishes the presence and status of a low-pressure switch and associated warning light, as shown in Figure B-9. The operations are defined below.

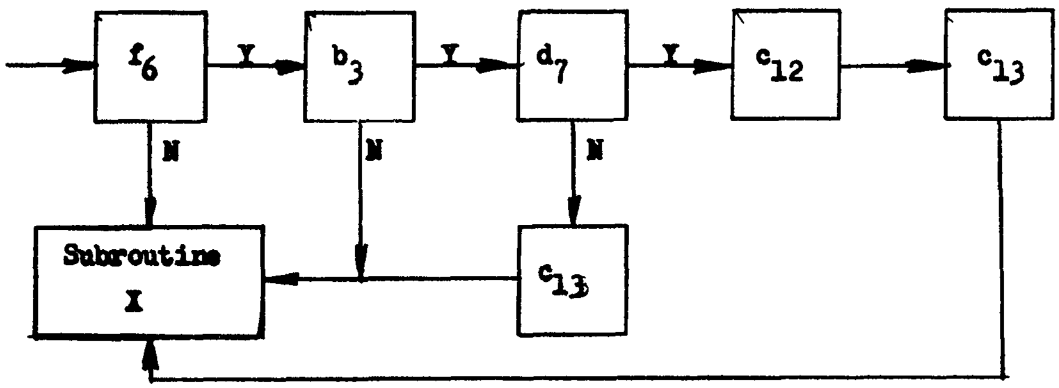

Figure B-9 - Subroutine IX for Pneumatic System Simulation

f_6 - Is a low pressure warning system present? (test V_6).

b_3 - Is $P_{i,j,k+1,\ell,m+1} \leq P_{p,low}$? The pressure at which the warning light comes on, $P_{p,low}$, is obtained from the flight handbook.

d_7 - Is a-c electrical power available for warning light? (test U_9).

c_{13} - Set warning light to ON.

c_{13} - Set warning light to OFF.

J. Subroutine X

Subroutine X establishes the presence and status of a pressure transmitter and the associated indicator. Provision is made for an instructor to fail the pilot's indicator. The flow chart is given in Figure B-10; the operations are defined below.

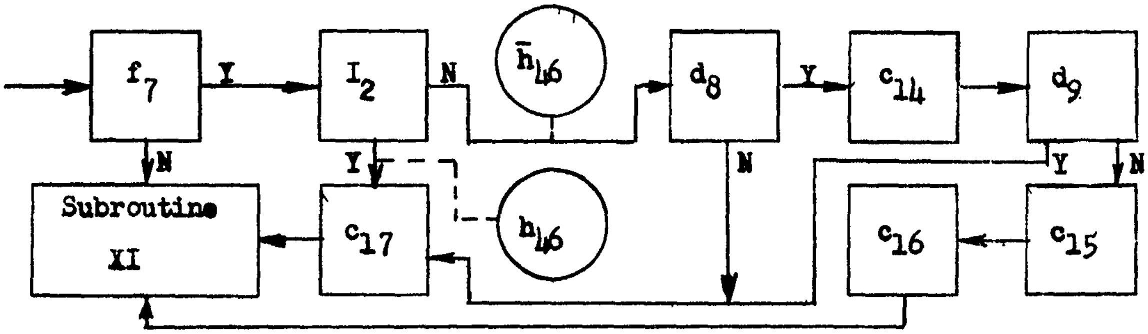

Figure B-10 - Subroutine 10 for Pneumatic System Simulation

- f_7 - Is a pressure gage present? (test V_7).
- I_2 - Is instructor's indicator fail switch on? (test U_{10}).
- h_{46} - Set instructor's indicator fail light to ON.
- c_{17} - Pressure gage inoperative.
- $\bar{h}_{46}$ - Set instructor's indicator fail light to OFF.
- d_8 - Is d-c electrical power available for pressure transmitter? (test U_{11}).
- d_9 - Is a-c electrical power available for pressure gage? (test U_{12}).
- c_{16} - Transfer system pressure status to indicator.

K. Subroutine XI.

Subroutine XI determines the proper sequence of subsystem computations. It is also used in connection with the instructor's ground charge switch to establish, initially, individual bottle pressures. The flow chart is presented in Figure B-11, and the operations are defined below.

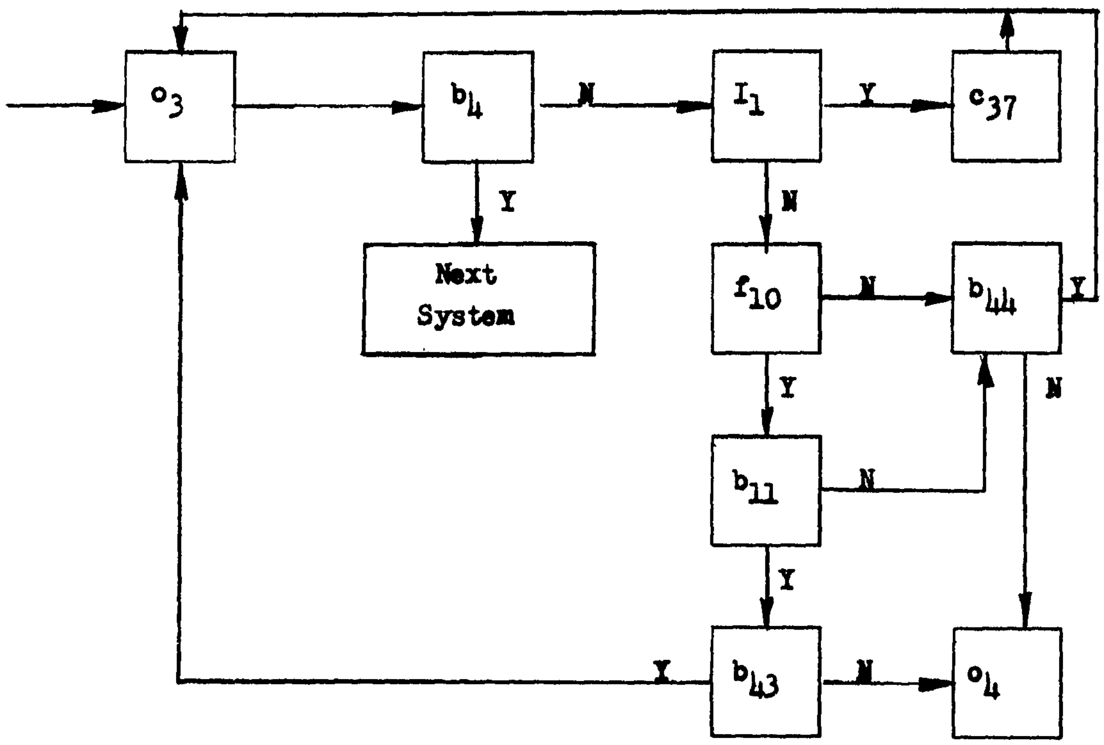

Figure B-11 - Subroutine XI for Pneumatic System Simulation

- o_3 - Increase the subsystem index; that is, replace ℓ by $\ell+1$.
- b_4 - Test index; have all subsystems been computed?
- I_1 - Is instructor's ground charge switch on? (test U_{13}).
- c_{37} - Set j^{th} bottle pressure to P_{pN}.
- f_{10} - Is a priority valve present? (test V_8).
- b_{11} - Is $P_{i,j,k+1,\ell,m+1} \leq P_{pV}$? Is priority valve to determine special distribution of pressure? The pressure at which the priority valve begins to function (P_{pV}) may be found in the aircraft flight handbook or maintenance handbook for the particular pneumatic system.
- b_{43} - Test the digit of the modified third control word according to the subsystem index. Is this digit zero?

The third control word of the pneumatic system determines which of all the pneumatic subsystems are present in the aircraft being simulated. This control word is formed manually or by an assembly program. Each digit of this control word is associated with one of the sub-

systems previously listed. A zero digit is used to indicate the absence of the associated subsystem. A units digit is used to indicate the presence of the associated subsystem.

A modified control word defining the subsystems for which power is available when the priority valve is acting must also be formed. When the priority valve tests are satisfied, this modified control word is used instead of the usual one. It is identical with the usual one except that it has zero digits for subsystems to which pneumatic power is unavailable during priority valve action.

The association between digits of this control word and the pneumatic subsystems is shown below.

Digit	Subsystem no.
W_1	1
W_2	2
W_3	3
W_4	4
.	.
.	.
.	.
W_{17}	17

o_4 - Transfer to $(\ell+1)^{th}$ subsystem (Subroutine XII).

b_{44} - Test digit of third control word according to subsystem index. Is this digit zero? The subsystem indexer determines which digit to test.

NOTE

The above transfer is actually to the $(j+1)^{th}$ bottle associated with the $(\ell+1)^{th}$ subsystem.

L. Subroutine XII

Subroutine XII performs the computations associated with providing pneumatic pressure to the proper subsystems. Individual bottle and main system pressures are adjusted according to each subsystem's demands.

Subroutine XII is divided into two parts: XII-a is the general subsystem simulation, while XII-b is a special subsystem simulation not included in XII-a. Subroutine XII-a is presented in a general form with the understanding that it be applied to each subsystem as required in the simulation of a particular aircraft.

1. Subroutine XII-a.

Subroutine XII-a is diagrammed in Figure B-12; the operations are defined below.

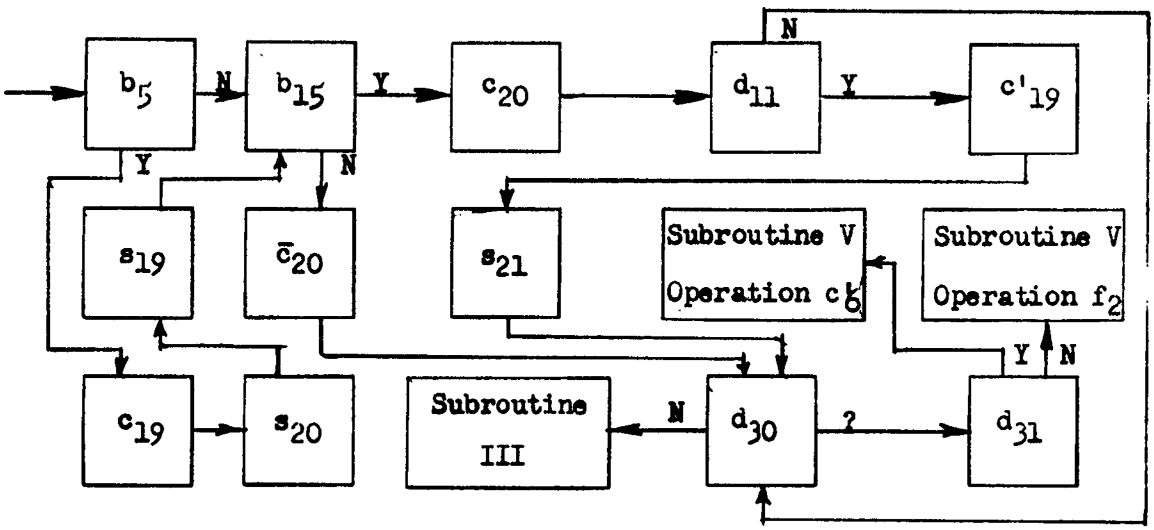

Figure B-12 - Subroutine XII-a for Pneumatic System Simulation

b_5 - Is the $(j+1)^{th}$ bottle pressure less than the main system pressure? That is, is $P_{i-1,j+1,k+1,\ell+1,m+1} < P_{i,j,k+1,\ell,m+1}$?

c_{19} - Compute the $(j+1)^{th}$ bottle pressure and adjust the main system pressure.

If the main system pressure is $P_{i,j,k+1,\ell,m+1}$, the main system volume of air is V_s, the $(j+1)$th bottle pressure is $P_{i-1,j+1,k+1,\ell+1,m+1}$ from the previous computation cycle, and the volume of air in the $(j+1)^{th}$ bottle is V_{j+1} (as obtained from flight

handbook), the following equation may be written to describe the movement of compressed air from the main system to the $(j+1)^{th}$ bottle:

$$P_{i,j+1,k+1,\ell,m+1}\,(V_s + V_{j+1}) = P_{i,j,k+1,\ell,m+1}\,(V_s)$$

$$+ P_{i-1,j+1,\ell+1,m+1}\,(V_{j+1}),$$

where energy loss due to heat is neglected. The main system mass of air becomes

$$m_{i,j+1,k+1,\ell,m+1} = \frac{(P_{i,j+1,k+1,\ell,m+1})(m_{i,j,k,\ell,m})}{P_{i,j,k,\ell,m}} .$$

s_{19} - Store $P_{i,j+1,k+1,\ell,m+1}$ as a new system pressure and as new $(k+1)^{th}$ bottle pressure.

s_{20} - Store $m_{i,j+1,k+1,\ell,m+1}$ as new system mass of air.

d_{11} - Is the subsystem control valve open? Test the proper digit (U_{15} through U_{30}) according to the subsystem index.

b_{15} - Is $P_{i,j+1,k+1,\ell,m+1} > \Delta P_{\ell+1}/\Delta t$? The subsystem loads, $\Delta P_{\ell+1}/\Delta t$, are obtained from the aircraft manufacturer's design data, and are taken as fixed pressure decrement rates; t_s is the simulation cycle time.

c_{20} - Set proper control word digit of $(\ell+1)^{th}$ subsystem to 1 to indicate that pneumatic power is available.

$\overline{c}_{20}$ - Set proper control word digit of $(\ell+1)^{th}$ subsystem to zero to indicate that pneumatic power is unavailable.

c_{19} - Decrease $(j+1)^{th}$ bottle pressure by $(\ell+1)^{th}$ actuator's requirements, $(\Delta P_{\ell+1}/\Delta t)ts$.

s_{21} - Store new bottle pressure as $P_{i,j+1,k+1,\ell+1,m+1}$.

d_{30} - Steady rate to be used for next subsystem? (test U_{31}).

d_{31} - Steady rate to be used for next subsystem? (test U_{32}).

2. <u>Subroutine XII-b</u>.

Subroutine XII-b performs the computations for the pneumatic pressure output to the emergency flaperette system (F9F). The subroutine is shown in the flow chart in Figure B-13; the operations are defined below.

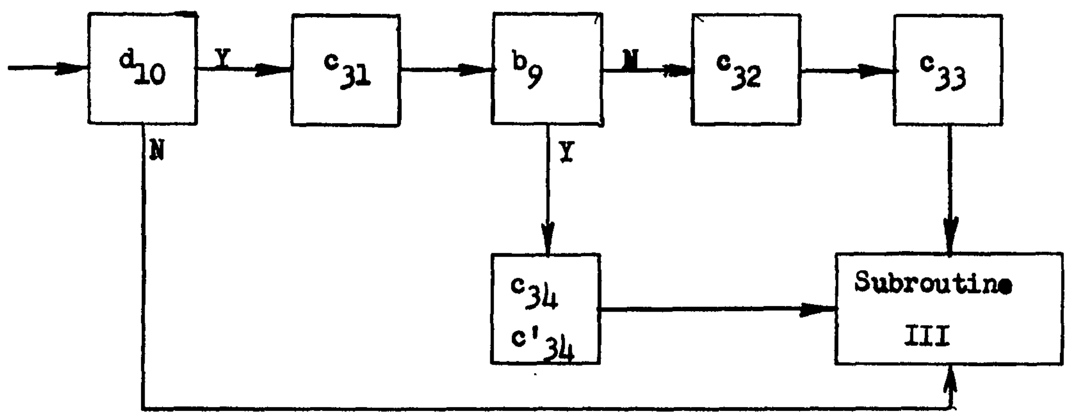

Figure B-13 - Subroutine XII-b for Pneumatic System Simulation

d_{10} - Is emergency flaperette power control valve open? (test U_{14}).
c_{31} - Counter (add one for each pass).
b_9 - Is counter greater than maximum? The maximum number of applications is obtained from the flight handbook.
c_{32} - Output to flaperette system. Set control-word digit of flaperette system to 1 to indicate pneumatic power available.
c_{33} - Output to flaperette gage; maximum minus counter.
c_{34} - Set output to flaperette gage to zero.
c'_{34} - Set control-word digit of flaperette system to zero to indicate pneumatic power unavailable.

The preparation of input data for simulating the F4H pneumatic system is shown below.

Digit	Value	Branch identification	Subroutine in which defined
V_1	1	f_1	III
V_2	1	f_{11}	IV
V_3	1	f_2	V
V_4	0	f_3	V
V_5	1	f_4	V
V_6	0	f_6	IX
V_7	1	f_7	X
V_8	0	f_{10}	XI

The normal system pressure, from the flight handbook, is P_{PN} = 3000 psi. Similarly, P_{Cmin} and P_{Cmax} are 2700 and 3000 psi, respectively. P_{Pmax} = 3500 psi.

The third control word of the pneumatic system is again formed from information obtained from the flight handbook.

Digit	Value	Subsystem no. (defined on p-10)
W_1	0	1
W_2	1	2
W_3	1	3
W_4	1	4
W_5	1	5
W_6	1	6
W_7	0	7
W_8	0	8
W_9	1	9
W_{10}	1	10
W_{11}	1	11
W_{12}	0	12
W_{13}	0	13
W_{14}	0	14
W_{15}	0	15
W_{16}	0	16
W_{17}	1	17

From the flight handbook, the individual bottle volumes are:

Subsystem no.	Volume (convert to cu. ft)	
2 and 3	100 cu in.	
4	V_g = 800 cu in.	
5	200 cu in.	
6	150 cu in.	
9	15 cu.in.	
10	15 cu in.	
11	400 cu in.	1 bottle
17	400 cu in.	

SECTION VIII. APPENDIX C - DETAILED SIMULATION FLOW CHART FOR GENERAL HYDRAULIC SYSTEM SIMULATION

The types of operations represented by the flow-chart symbols are the same as those defined in Appendix A.

A. Subroutine I.

Subroutine I determines whether the hydraulic system is to be simulated during the i^{th} cycle and, if so, what type of simulation should be done. General initialization of the main routine is also performed here. The flow chart is given in Figure C-1, and the operations are defined below.

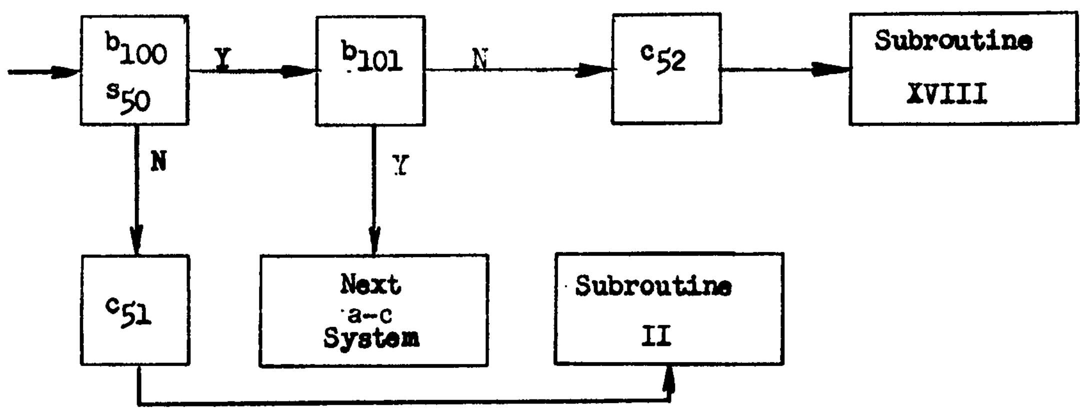

Figure C-1 - Subroutine I for Hydraulic System Simulation

b_{100} - Is steady-rate to be simulated? Does $W_{hi} - W_{hi-1} = 0$? W_{hi} is the first control word of the hydraulic system simulation for the i^{th} cycle. The digits will be denoted by q_1, q_2, ... and are related to "P," "I," and "d" decisions, as indicated below. The instructor's leak switch may have a third position for initially charging the hydraulic systems. This switch would override b_{100} to produce a "no" branch.

Digit	Decision identification	Subroutine in which defined
q_1	p_{50}	II
q_2	d_{50}	II
q_3	d_{51}	II
q_4	d_{52}	II
q_5	d_{58}	II
q_6	p_{51}	IV
q_7	d_{54}	IV
q_8	d_{55}	V
q_9	d_{56}	VII
etc.	etc.	etc.

NOTE

Since the use of control words has been illustrated and since further illustration would be repetitious, control words will be indicated hereafter simply by defining the first few digits of each. Their exact composition will be similar to the previous ones and will be formed in exactly the same manner.

s_{50} -- Store W_{h_i} as $W_{h_{i-1}}$.

b_{101} - Steady-state test. Test W_{h_i} for condition indicating that hydraulic systems are not being used.

c_{51} - Initialization includes resetting indexes, d_{69}, Subroutine XIV, to "N," c_{167}, etc.

c_{52} - Initialize steady-rate computations. Includes setting d_{69} Subroutine XIV to "Y," etc.

B. Subroutine II.

Subroutine II determines whether the pilot's emergency pump control is on and, if so, performs the simulation. It includes both ram air and electrically driven pumps. The flow chart is presented in Figure C-2; the operations are defined below.

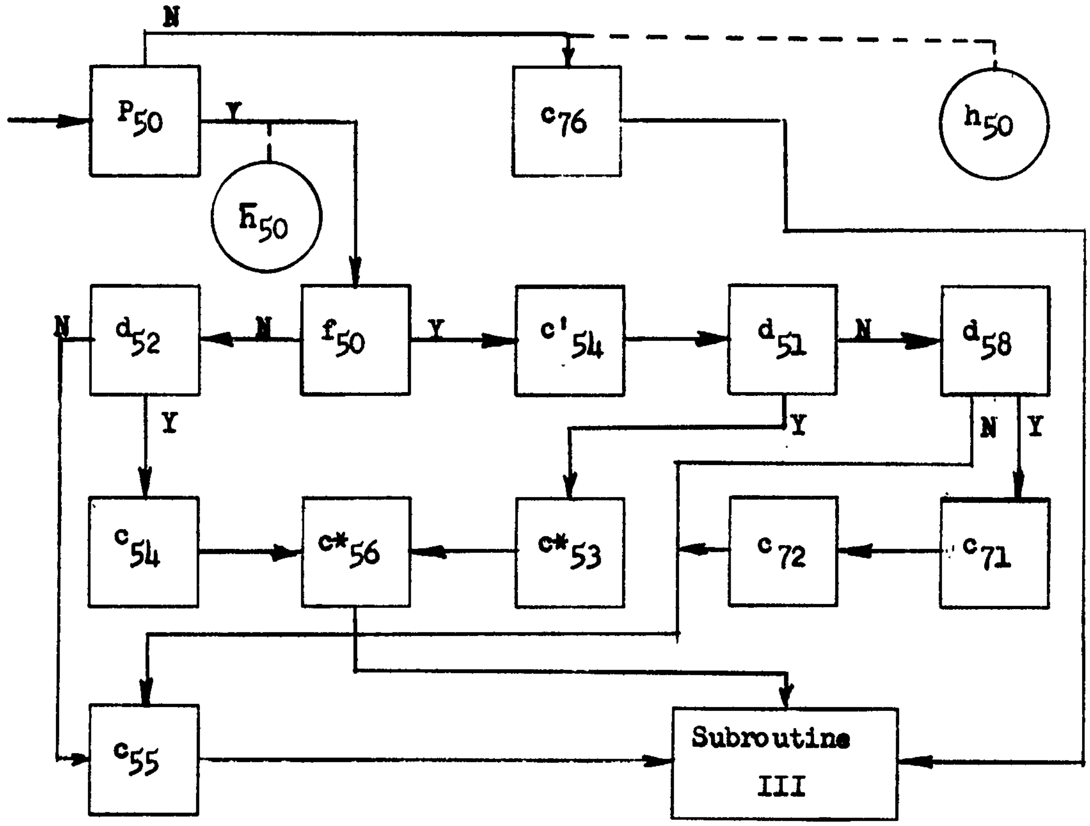

Figure C-2 Subroutine II for Hydraulic System Simulation

P_{50} - Is the pilot's emergency pump switch on? (test q_1).
h_{50} - Set instructor's indicator associated with P_{50} to ON.
c_{76} - Resets; includes setting instructor's emergency pump indicator to OFF, and resetting q_3, c_{53}, c_{57}, and U_{17}.
f_{50} - Is ram air needed for emergency pump operation (test r_1).

The hydraulic system second control word is similar to the corresponding control word for the flap system. The association between its digits and f-type branches is indicated below.

Digit	Branch identification	Subroutine in which defined
r_1	f_{50}	II
r_2	f_{51}	VII
r_3	f_{52}	IV
etc.	etc.	etc.

d_{51} - Is ram air available? (test q_3).

c^*_{53} - Ram-air turbine output to aerodynamics.

c^*_{56} - Compute emergency pump volume increment. An emergency hydraulic pump output or volume rate of delivery $\Delta V_{kp}/\Delta t$ is constant (C_2) up to an outlet pressure of Ph_o; it then decreases linearly to zero at the normal system pressure, Ph_n. This rate of delivery is given by

$$\frac{\Delta V_{kp}}{\Delta t} = C_2, \qquad (0 \leq P_{i,j,k,\ell,m,p} \leq Ph_o) \tag{C-1a}$$

$$\frac{\Delta V_{kp}}{\Delta t} = A_2 + B_2\,(P_{i,j,k,\ell,m,p}), (Ph_o < P_{i,j,k,\ell,m,p} \leq Ph_n) \tag{C-1b}$$

and

$$\frac{\Delta V_{kp}}{\Delta t} = 0, \qquad (P_{i,j,k,\ell,m,p} > Ph_n) \tag{C-1c}$$

where $P_{i,j,k,\ell,m,p}$ is the k^{th} hydraulic system pressure for the j^{th} associated accumulator during the i^{th} computation cycle, "p" the pump number, "ℓ" the load number, and "m" the instructor-inserted leak number.

Constants C_2, Ph_o, and Ph_n are given in the aircraft handbook of maintenance instructions for the hydraulic system. They may also be given in the trainer systems report. A_2 and B_2 are given by

$$A_2 = C_2\,(1 - \frac{Ph_o}{Ph_o - Ph_n}) \tag{C-2a}$$

and

$$B_2 = \frac{C_2}{Ph_o - Ph_n}. \tag{C-2b}$$

Multiplying Equations 1a, 1b, and 1c by the time elapsed since the last emergency pump simulation gives the desired volume increment.

d_{52} - Is a-c electrical power available? (test q_4).
c_{54} - Set signal for electrical power. Set proper control word digit to 1.
c_{55} - Set emergency pump volume increment to zero.
d_{58} - Is pneumatic pressure available for lowering ram-air turbine? (test q_5).
c_{71} - Set control word digit U_{17} to 1.
c_{72} - Time delay for ram air turbine extension. At end of delay, set q_3 to 1.
c'_{54} - Set signal for no electrical power. Set proper control word digit to zero.

C. Subroutine III.

Subroutine III performs the computations for the instructor's hydraulic system fail option. Figure C-3 is the subroutine flow chart; operations are defined below.

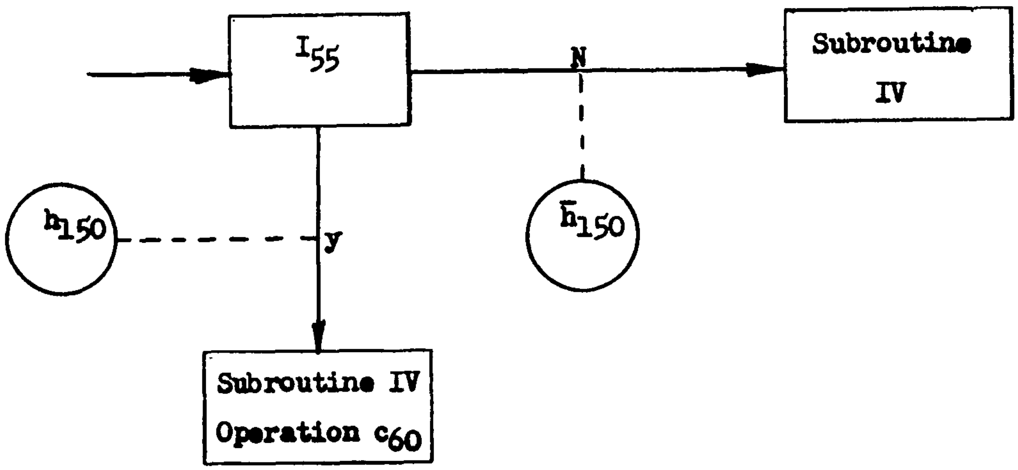

Figure C-3 - Subroutine III for Hydraulic System Simulation

I_{55} - Is instructor's hydraulic fail switch on?
h_{150} - Set instructor's hydraulic fail switch indicator to ON.

D. Subroutine IV.

Subroutine IV determines whether there is a fluid shutoff control to stop hydraulic fluid flow to the pump being simulated and, if so, the status of that control. Figure C-4 shows the block diagram, while the operations are defined below.

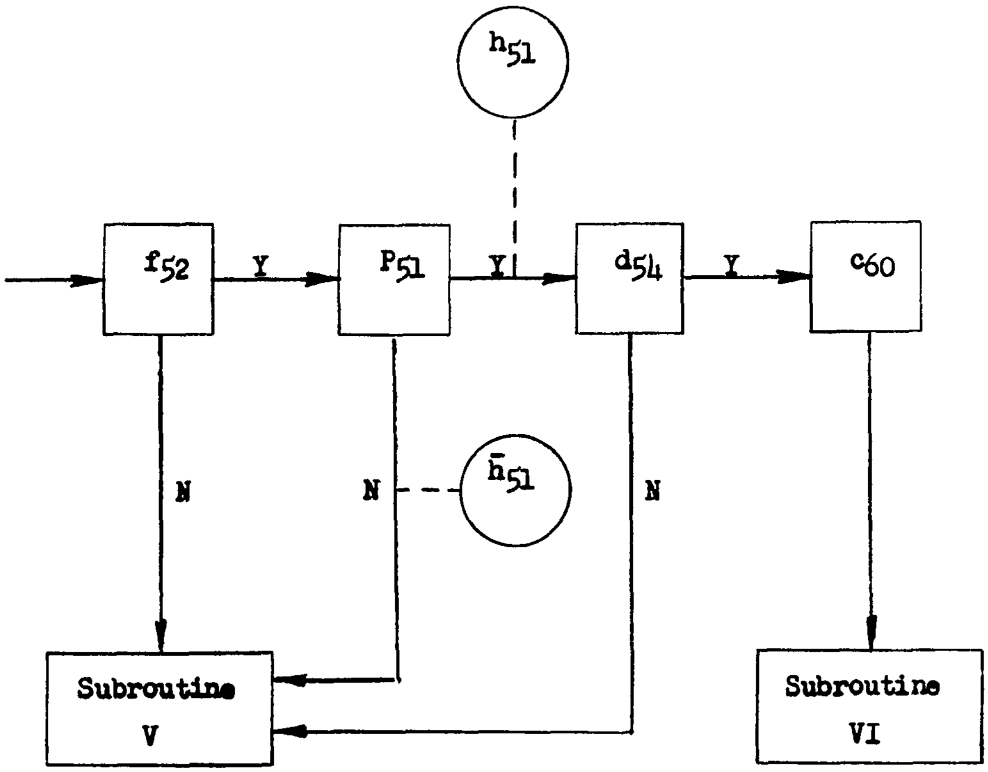

Figure C-4 - Subroutine IV for Hydraulic System Simulation

f_{52} - Is a fire-wall valve present? (test r_3).
p_{51} - Is pilot's fire-wall valve switch ON? (test q_6).
d_{54} - Is electrical power available for valve? Test proper control word.
c_{60} - Associated pump volume increment, $\Delta V_{kp} = 0$.
h_{51} - Set instructor's indicator associated with P_{51} to ON.

E. Subroutine V.

Subroutine V, the pump pressure subroutine, computes the pressure increment produced by the pump being simulated. Engine rpm, fluid quantity, and pressure are considered, as shown in Figure C-5, the flow chart. The operations are defined below.

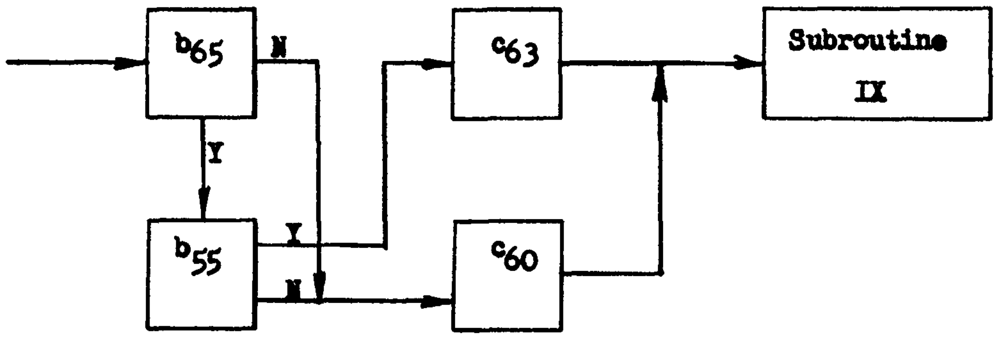

Figure C-5 - Subroutine V for Hydraulic System Simulation

b_{65} - Is engine rpm sufficient for pump output?
c_{63} - Pump volume increment computations.

Operation C_{56}, Subroutine II, describes the procedure for computing normal pump volume increments. Note that only one normal pump is simulated on each pass, in addition to the possibility of an emergency pump. It is therefore necessary that all pump data be initially stored so that the pump indexer can be used to select the proper pump data for the pump being simulated. The p^{th} pump of the k^{th} hydraulic system has a volume increment output denoted by ΔV_{kp}.

b_{55} - Is fluid quantity at or above normal operating level?
c_{60} - Set pump volume increment, $\Delta V_{kp} = 0$.

F. Subroutine VI.

Subroutine VI determines whether the instructor's leak switch is on and, if so, inserts a constant pressure decrement. Figure C-6 shows the flow diagram, with the operations being defined below.

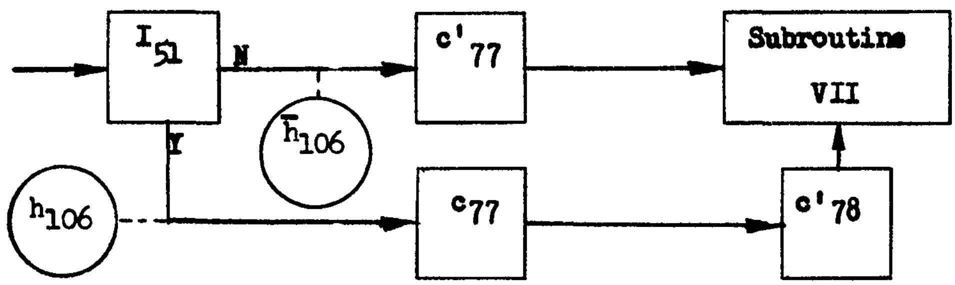

Figure C-6 - Subroutine VI for Hydraulic System Simulation

I_{51} - Is instructor's leak switch on?
h_{106} - Set instructor's leak switch indicator to <u>ON</u>.
c_{77} - Set volume decrement, ΔV_m.
$\bar{h}_{106}$ - Set instructor's leak switch indicator to <u>OFF</u>.
c'_{78} - Set quantity decrement for reservoir, $-\Delta Q_m$.
c'_{77} - Set quantity and volume decrements to zero: $\Delta V_m = \Delta Q_m = 0$.

G. Subroutine VII.

Subroutine VII computes the quantity of fluid available and sets the quantity gage when present. It includes the simulation of a replenishing system, as shown in Figure C-7, the flow diagram. Operations are defined below.

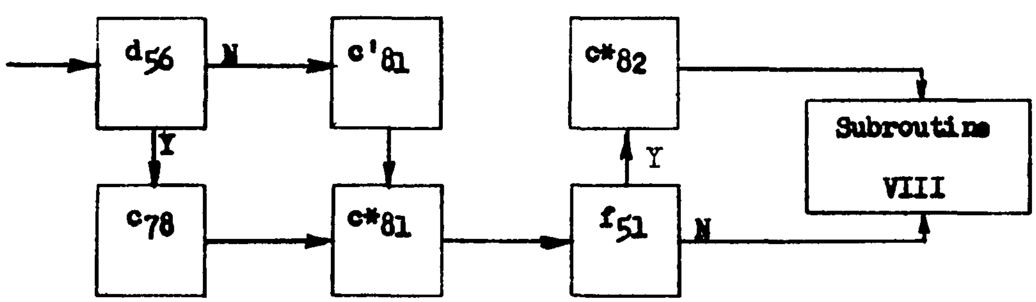

Figure C-7 - Subroutine VII for Hydraulic System Simulation

d_{56} - Is replenishing system operating? (test q_9).
c_{78} - Set quantity increment, ΔQ.
c^*_{81} - Add quantity increments or decrements, $\Delta Q - \Delta Q_m$.
c'_{81} - Set quantity increment to zero ($\Delta Q = 0$).
f_{51} - Is a fluid quantity indicator present? (test r_2).
c^*_{82} - Output to fluid quantity indicator.

H. Subroutine VIII.

The distribution of pump output volume to the accumulators associated with the pump is computed in Subroutine VIII. An accumulator indexer or counter is also present; system pressure is calculated as a function of fluid volume and maintained less than or equal to a preset maximum. The flow chart is given in Figure C-8; the operations are defined below.

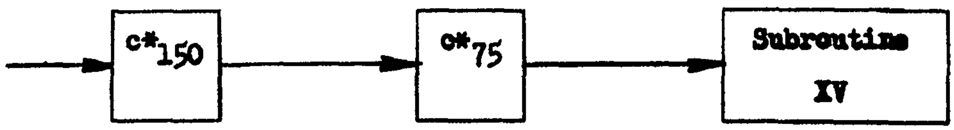

Figure C-8 - Subroutine VIII for Hydraulic System Simulation

c^*_{150} - Divide ΔV_{kp} by the number of accumulators associated with the p^{th} pump of the k^{th} hydraulic system; denote this result by $\overline{\Delta V}_{kp}$.
c^*_{75} - The volume of fluid in the j^{th} accumulator is given by

$$V_{i,j,k,\ell,m,p} = V_{i-1,j,k,\ell,m,p} - \Delta V_m + \overline{\Delta V}_{kp}.$$

I. Subroutine IX.

Subroutine IX computes the accumulator pressure associated with the system and loads being simulated. A pressure relief valve is also simulated. The subroutine flow chart is given in Figure C-9; the operations are defined below.

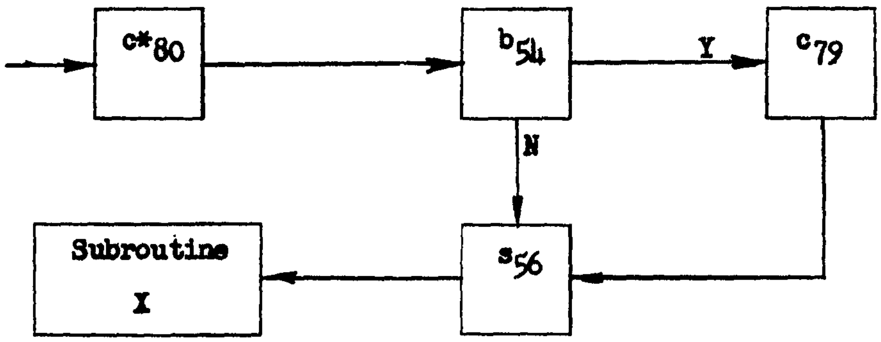

Figure C-9 - Subroutine IX for Hydraulic System Simulation

c^*_{80} - Compute accumulator and system pressure. The volume of the j^{th} accumulator of the p^{th} pump of the k^{th} hydraulic system is denoted by $V_{a,j,k,p}$. (These values are given in the aircraft maintenance handbook. The precharged accumulator has an air pressure $P_{a,j,k,p}$.) Boyles' law can now be applied to yield the accumulator and system pressure:

$$P_{h,i,j,k,\ell+1,m,p} = \frac{(V_{a,j,k,p})\ (P_{a,j,k,p})}{V_{a,j,k,p} - V_{i,j,k,\ell,m,p} + \left(\frac{\Delta V_{s,j,k,\ell+1,p}}{\Delta t}\right) ts} \qquad \text{(C-3)}$$

where $\Delta V_{s,i,j,k,\ell+1,p}/\Delta t$ is the volume rate requirement of the $(\ell+1)^{th}$ subsystem load, and t_s is the simulation cycle time. The indicated product is computed in Subroutine XVI.

b_{54} - Is the system pressure greater than a preset maximum? This maximum system pressure is given by the maintenance handbook.

c_{79} - Set system pressure to maximum.

s_{56} - Store $V_{i,j,k,\ell,m,p} + \left[\frac{\Delta V_{s,i,j,k,\ell+1,p}}{\Delta t}\right] ts$ as $V_{i,j,k,\ell+1,m,p}$.

J. Subroutine X.

Subroutine X determines whether there is a pump-pressure indicator and, if so, sets it to the pump pressure value. A selector switch is simulated so that all pump pressures can be read on a single indicator. An instructor indicator fail is also incorporated. The flow is diagrammed in Figure C-10, and the operations are defined below.

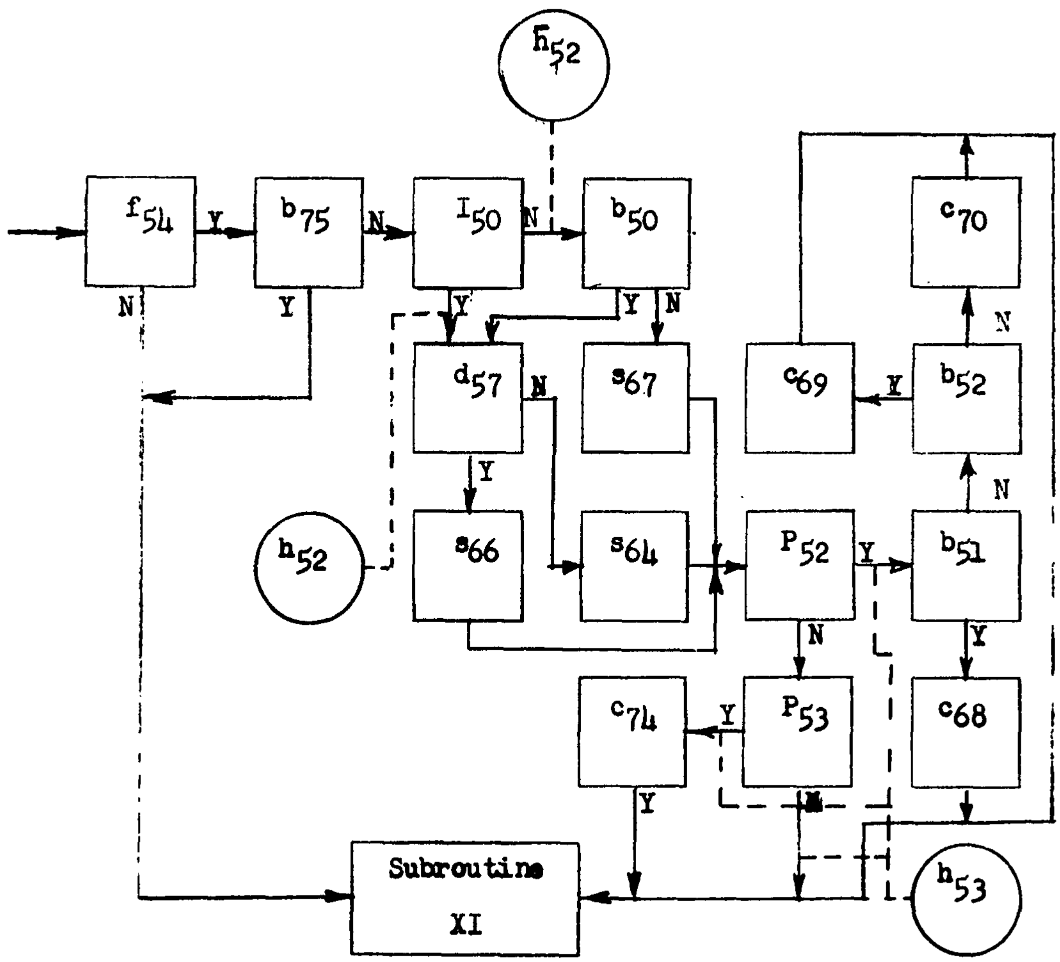

Figure C-10 - Subroutine X for Hydraulic System Simulation

f_{54} - Is a pump-pressure indicator present? (In future "P," "I," and "d" decisions and "f"-type branches, testing of the proper control word digits is implied.)

b_{75} - Has a subsystem load been computed corresponding to this accumulator?

I_{50} - Is instructor's pump indicator fail switch on?

h_{52} - Set instructor's pump indicator fail switch indicator to ON.

b_{50} - Is pump pressure less than preset minimum? At this point in the simulation (before loads are simulated), the pump pressure is equal to the corresponding accumulator pressure unless it has been failed by the instructor.

d_{57} - Is d-c electrical power available for indicator operation.

s_{64} - Set NO D-C for output to indicator. (Store.)

s_{66} - Set LOW for output to indicator. (Store.)

s_{67} - Set ON for output to indicator. (Store.)

NOTE

c_{64}, c_{66}, and c_{67} refer to the particular pump being simulated. Each pump has its own storage for output to indicator.

P_{52} - Is pump pressure selector set on ALL?

P_{53} - Is pump pressure selector set to the pump being simulated?

h_{53} - Set instructor's pump-pressure selector indicator.

c_{74} - Set pump-pressure indicator to last simulated pump output storage.

b_{51} - Is any pump output storage set to NO D-C?

c_{68} - Set pump pressure indicator to NO D-C.

b_{52} - Is any pump output storage set to LOW?

c_{69} - Set pump-pressure indicator to LOW.

c_{70} - Set pump-pressure indicator to ON.

K. Subroutine XI.

Subroutine XI sets the accumulator pressure gage, if present. The flow is shown in Figure C-11, and the operations are defined below.

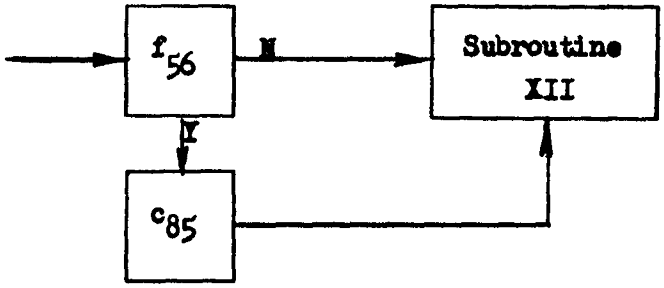

Figure C-11 - Subroutine XI for Hydraulic System Simulation

f_{56} - Is accumulator pressure gage present?
s_{85} - Store output to accumulator pressure gage.

L. Subroutine XII.

The low-pressure switches and warning lights, when present in the hydraulic system, are simulated in Subroutine XII. This subroutine computes the status of any automatic low-pressure control. The operations are defined below.

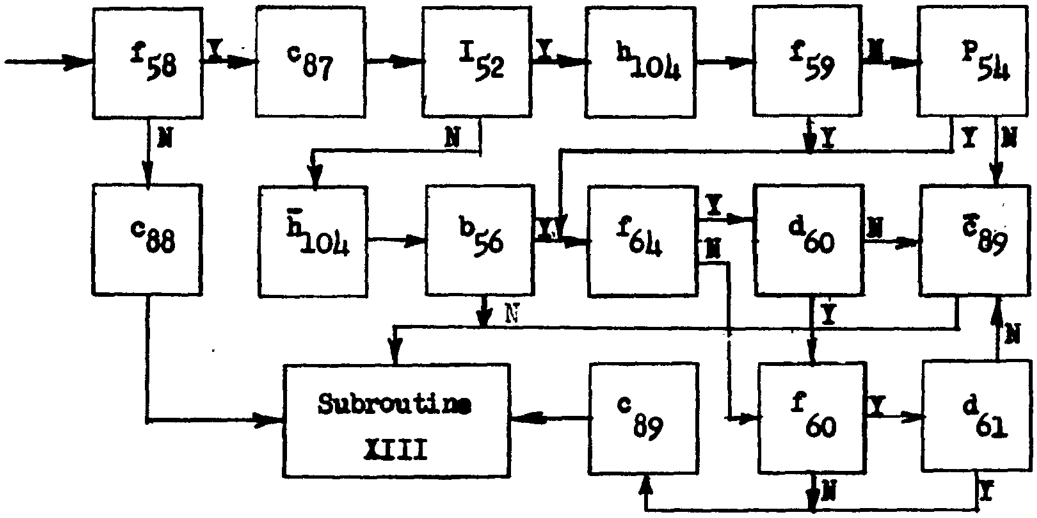

Figure C-12 - Subroutine XII for Hydraulic System Simulation

f_{58} - Is a low-pressure switch present?
I_{52} - Is instructor's low-pressure switch fail on?
h_{104} - Set instructor's low-pressure switch fail indicator to ON.
f_{59} - Is the switch output to an indicator light?
P_{54} - Is pilot's low-pressure switch on?
$\bar{c}_{89}$ - Set switch or light to OFF. If a switch is present that starts the emergency pump, this operation (also c_{89}) sets the control-word digit corresponding to P_{54}. However, a distinction between this and the pilot's switch setting of the control word digit must be made by the P_{54} test.
$\bar{h}_{104}$ - Set instructor's low-pressure switch fail indicator to OFF.
b_{56} - Is system pressure less than a preset low?
f_{64} - Is a-c electrical power needed?
d_{60} - Is a-c electrical power available?
f_{60} - Is d-c electrical power needed?
d_{61} - Is d-c electrical power available?
c_{87} - Set subroutine output for switch.
c_{88} - Set subroutine output for light.
c_{89} - Set switch or light to ON.

M. Subroutine XIII.

Subroutine XIII determines whether a main system pressure selector is present and, if so, determines its status. If the proper conditions are met, the system pressure indicator will be set. The instructor can fail the indicator directly or fail the circuit breaker controlling electrical power to the indicator. Figure C-13 is the subroutine flow chart, the functions for which are defined below.

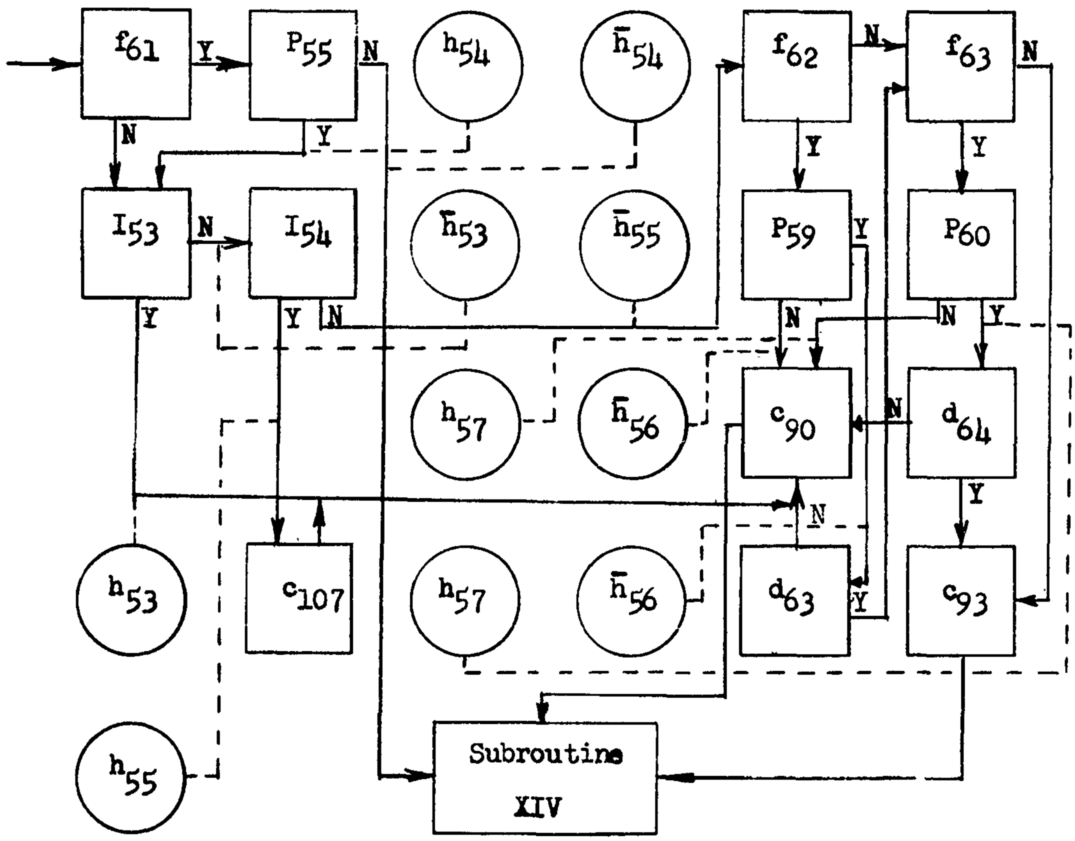

Figure C-13 - Subroutine XIII for Hydraulic System Simulation

f_{61} - Is a pressure gage selector present?
P_{55} - Is pilot's pressure gage selector set to the k^{th} system?
h_{54} - Set instructor's indicator associated with P_{55} to ON.
I_{53} - Is instructor's pressure gage fail switch on?
I_{54} - Is instructor's circuit breaker fail on?
h_{55} - Set instructor's indicator associated with P_{55} to ON.
c_{107} - Set pilot's circuit breaker (or breakers) to OFF.
f_{62} - Is a-c electrical power needed for gage or transmitter?
P_{59} - Is pilot's a-c circuit breaker on?
h_{56} - Set instructor's indicator associated with I_{54}.
f_{63} - Is d-c electrical power needed for gage or transmitter?
P_{60} - Is pilot's d-c circuit breaker on?
h_{53} - Set instructor's indicator associated with I_{53} to ON.

h_{57} - Set instructor's indicator associated with P_{60} to ON.
c_{93} - Set gage to system pressure.
d_{63} - Is a-c electrical power available?
d_{64} - Is d-c electrical power available?
c_{90} - Set pressure gage inoperative.

N. Subroutine XIV.

Both manual (pilot controlled) and automatic priority valves are simulated in Subroutine XIV. This subroutine can modify the order or number of loads that can be simulated for each hydraulic system. The flow is charted in Figure C-14, while the operations are defined below.

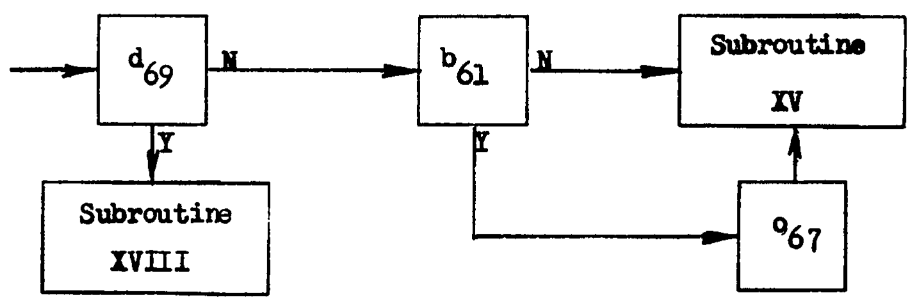

Figure C-14 - Subroutine XIV for Hydraulic System Simulation

b_{61} - Is a priority valve closed? This function includes tests of pressure and pilot switch controlling priority valve.
o_{67} - Set modified subsystem control word.
d_{69} - Is simulation in steady-rate condition?

O. Subroutine XV.

Subroutine XV determines which loads are associated with the k^{th} hydraulic system and the j^{th} accumulator. The operations of this Subroutine, which is shown in Figure C-15, are defined below.

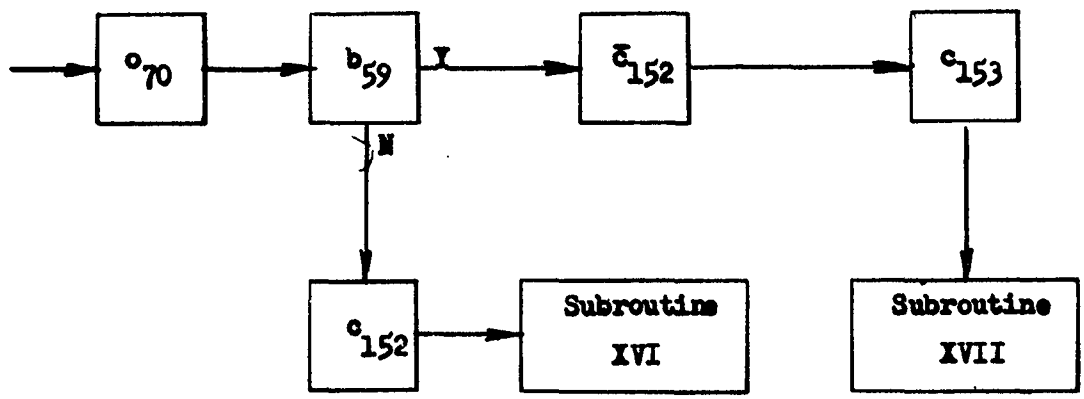

Figure C-15 - Subroutine XV for Hydraulic System Simulation

o_{70} - Increase the subsystem index, ℓ , to ℓ+1. A control word similar to the third control word of the pneumatic system could be used for each hydraulic accumulator.

b_{59} - Have all subsystems of this system accumulator been simulated? Test index or a special digit of the control word.

$\bar{c}_{152}$ - Set b_{75} Subroutine X to no.

c_{152} - Set b_{75} Subroutine X to yes.

c_{153} - Reset subsystem index.

P. Subroutine XVI.

Subroutine XVI simulates the hydraulic subsystems and includes multiple actuator computations. The flow chart is shown in Figure C-16; the operations are defined below.

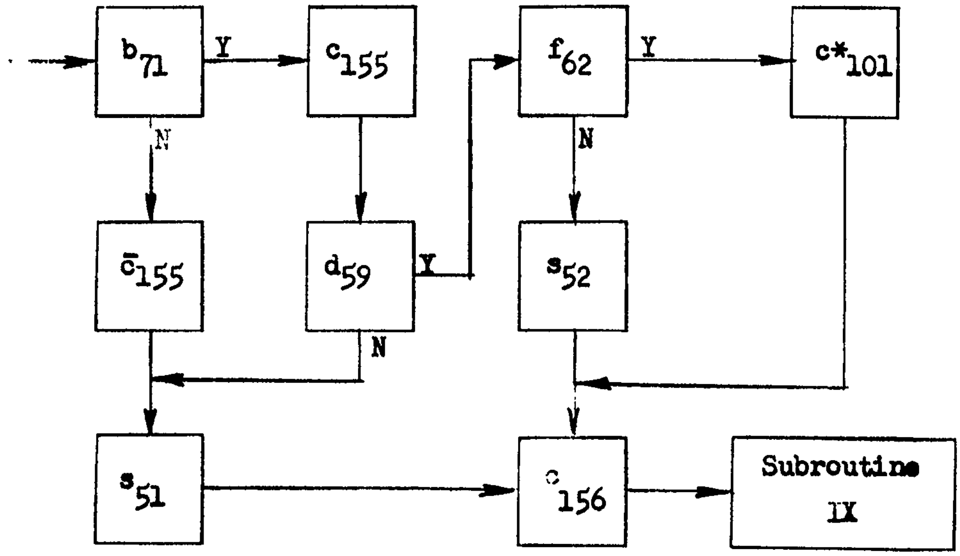

Figure C-16 - Subroutine XVI for Hydraulic System Simulation

- b_{71} - Is $V_{i,j,k,\ell,m,p} > (\Delta V_{s,j,k,\ell+1,p})\ \Delta t/ts$? The subsystem loads are volume rate decrements given in the aircraft manufacturer's hydraulic systems report.
- c_{155} - Set control-word digit of $(\ell+1)^{th}$ subsystem to indicate hydraulic power is available.
- $\bar{c}_{155}$ - Set control-word digit of $(\ell+1)^{th}$ subsystem to indicate hydraulic power is unavailable.
- d_{59} - Used with subsystem indexer. Is $(\ell+1)^{th}$ subsystem control valve open?
- s_{52} - Store $(\Delta V_{s,j,k,\ell+1,p})$ $ts/\Delta t$ for Subroutine IX.
- s_{51} - Store $(\Delta V_{s,j,k,\ell+1,p})$ $ts/\Delta t = 0$ for Subroutine IX.
- c_{156} - Sum loads (volume) for all subsystems of j^{th} accumulator.
- f_{62} - Is the $(\ell+1)^{th}$ subsystem powered by more than one hydraulic system accumulator?
- c^*_{101} - Modify the $(\ell+1)^{th}$ subsystem requirements. This operation proportions the total $(\ell+1)^{th}$ load according to the number of actuators being powered, and stores this value for Subroutine IX.

NOTE

It is assumed that computation cycle time will be fast enough to permit one pass through Subroutine VIII for each accumulator associated with a given pump. If sufficient continuity is not obtained, it may be necessary to perform operation c_{75} for each subsystem. This will necessitate modification of $\Delta V_{k,p+1}$ according to the computation time between subsystems.

Q. Subroutine XVII.

Subroutine XVII tests for the end of accumulator, pump, and system loops. Figure C-17 presents the flow chart and the operations are defined below.

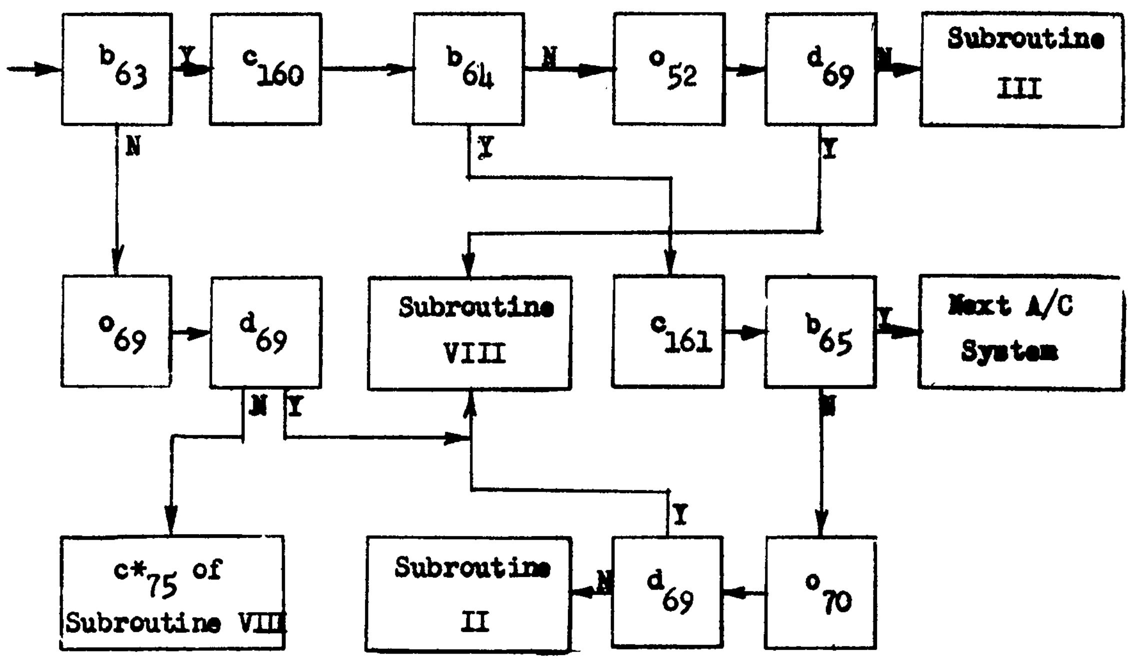

Figure C-17 - Subroutine XVII for Hydraulic System Simulation

b_{63} - Have all accumulators of the k^{th} system and p^{th} pump been simulated?
c_{69} - Advance accumulator index, j, to j+1.
c_{160} - Reset accumulator index.
b_{64} - Have all pumps of the k^{th} system been simulated?
c_{52} - Advance pump index, p, to p+1.
c_{161} - Reset pump index.
b_{65} - Have all hydraulic systems been simulated?
c_{70} - Advance system index, k, to k+1.
d_{69} - Is simulation in steady-rate condition?

R. Subroutine XVIII.

Subroutine XVIII (see Figure C-18) provides the computations for steady-rate simulation. The operations are defined below.

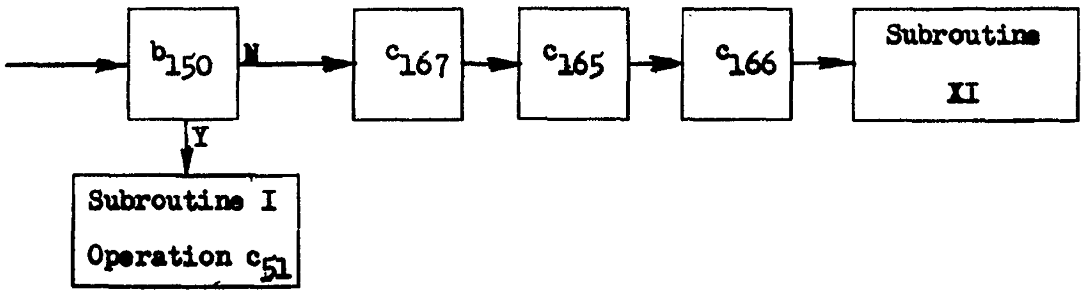

Figure C-18 - Subroutine XVIII for Hydraulic System Simulation

c_{165} - Apply c_{75} with proper indexes.
c_{166} - Apply Equation c-3 from c_{80}, with $(\Delta V_{s,j,k,\ell+1,p})$ ts/Δt replaced by proper sum obtained in c_{156}.
b_{150} - Have maximum number of steady-rate passes been made?
c_{167} - Counter; add one each pass.

SECTION IX. APPENDIX D - ENGINE CONTROL SYSTEMS

A. Nomenclature.

1. Symbols.

K = Algebraic constant
Q = Torque with respect to engine rotor
P = Pressure
T = Temperature
W_f = Main engine fuel flow
W_{f_r} = Afterburner fuel flow
A = Area
N = Engine rotor speed
α = Throttle position

2. Subscripts (for engine stations).

2 = Compressor inlet
3 = Compressor discharge
5 = Turbine discharge
8 = Jet nozzle throat
B = Burner
x = 2, 3, or B, as designated in text

3. Lower-case letters.

Lower-case letters a_i and b_i are used to denote "true" conditions. Each a_i and b_i are defined in the text; for example, a_9: denotes that fuel shutoff valve "A" is open, and $\acute{a}_9$ signifies that valve "A" is closed.

Lower-case c is used to designate a computation or storing process; for example, c_{36} - $N_{D_{max}} = f_1(T_2)$ means: evaluate $f_1(T_2)$ to find $N_{D_{max}}$. $N_{D_{max}}{}^{**}$ is then stored permanently or temporarily, as required to facilitate later computations involving $N_{D_{max}}$.

4. Superscripts.

Superscripts*, **, and *** are used to denote intermediate computations used in evaluating the variable to which the superscript is applied; for example, a_9^* and $N_{D_{max}}{}^{**}$ might be used in determining whether a_9 is "true" or "false," or while computing $N_{D_{max}}$, respectively.

B. Starting Routine.

The starting routine has been divided into nine subroutines, arranged as shown below in Figure D-1.

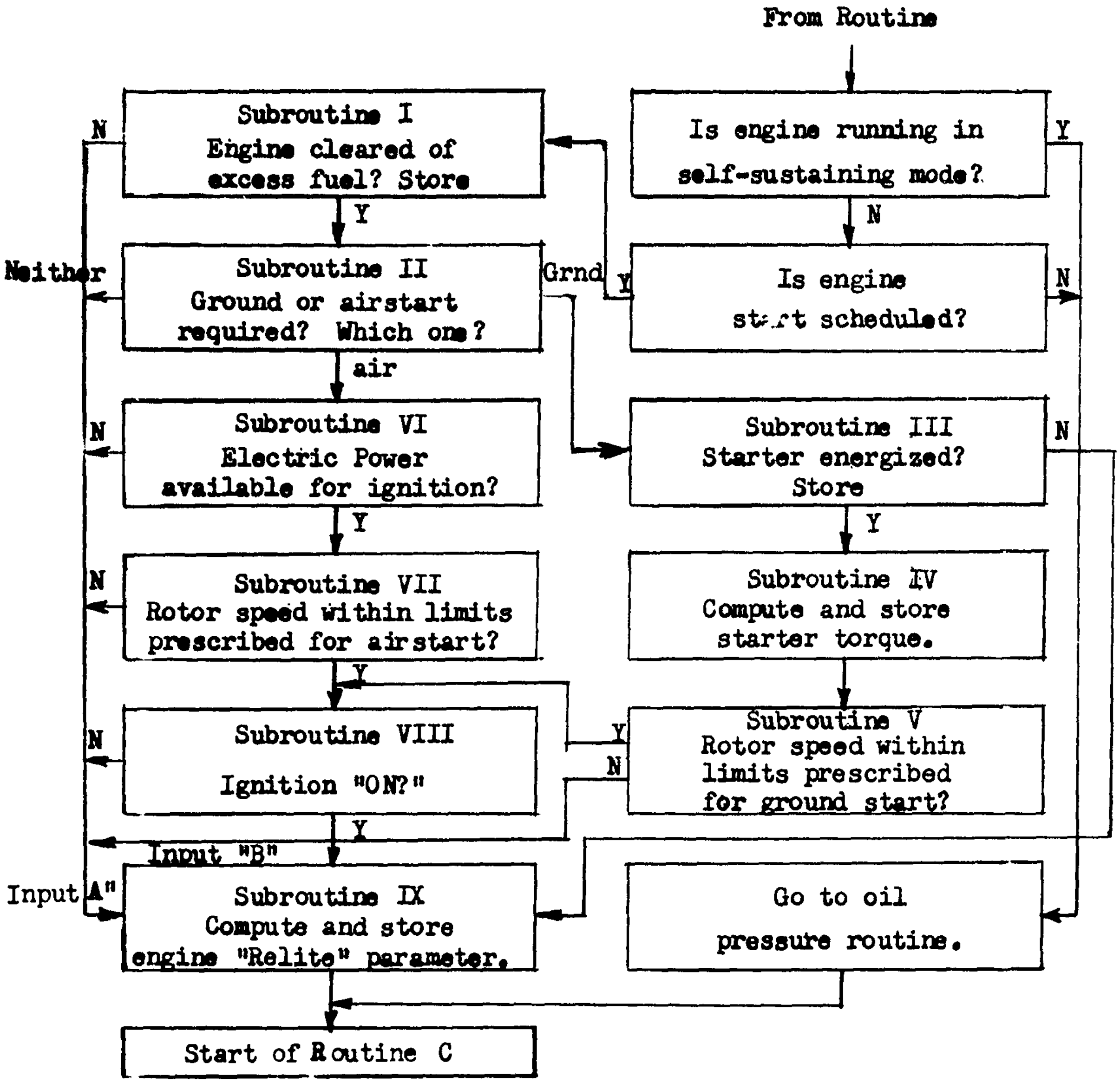

Figure D-1 - Starting Routine

1. Subroutine I - Engine Cleared of Excess Fuel?

Flight handbooks imply that the aircraft engine be cleared of excess fuel to increase the chances of obtaining a successful air start following an engine flameout. Motoring procedures are also outlined in the handbooks so that the pilot can clear the engine of excess fuel when emergencies, such as evidence of an engine fire following an engine shutdown, arise with the aircraft grounded.

The digital simulation routine for the engine-clearing procedure is shown in Figure D-2. The following facts, which are related to this and subsequent subroutines, are mentioned here for clarity.

1. If the instructor does not intervene, the student pilot must clear the engine of excess fuel to start the engine. This applies to ground starts as well as to air starts.
2. The instructor can clear the engine of excess fuel by pressing the ENGINE CLEAR button on his console when he deems it unnecessary for the pilot to follow the engine-clearing procedure prior to starting the engine. Of course, the ENGINE CLEAR button should not be used when an air start is required by the pilot.
3. As simulated herein, the pilot can clear the engine of excess fuel by shutting off the engine fuel supply while a preselected rotor speed is obtained either by windmilling or by using the engine starter.

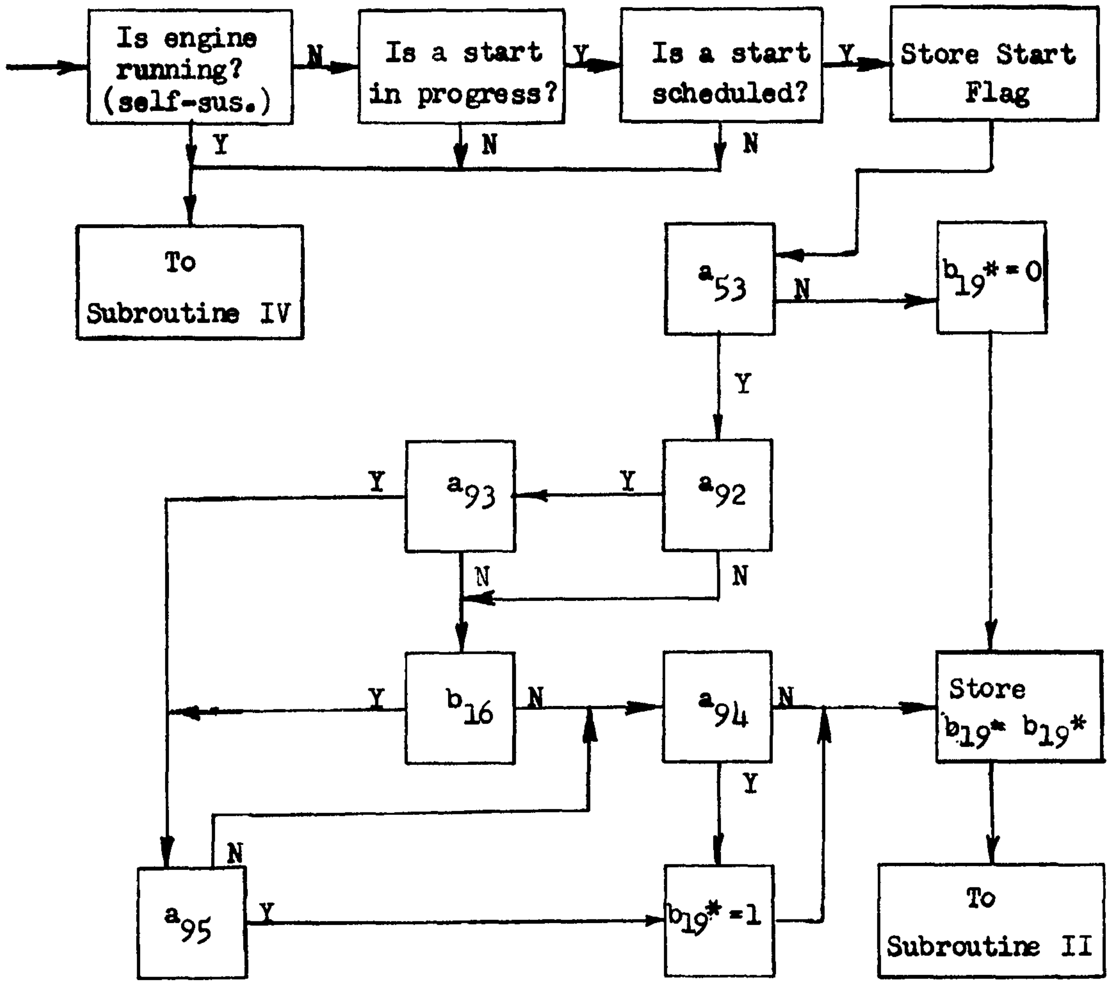

Figure D-2 - Subroutine I for Clearing Engine of Excess Fuel

The operations used in Figure D-2 are defined below.

a_{53} - Engine flameout.
a_{92} - Engine-start detent provided on throttle quadrant.
a_{93} - Fuel tank selector switch turned to OFF.
a_{94} - ENGINE CLEAR button depressed by instructor.

a_{95} - $N > K_1$, where K_1 is the minimum rotor speed at which the engine can be cleared.
b_{16} - Throttle set to OFF.
b_{19} - Engine cleared of excess fuel.

2. Subroutine II - Ground or Air Start Required? Which One?

In the digital simulation, it is necessary to determine whether or not the engine is running, and, if not, whether an air start or a ground start is required. In addition, the stage to which a ground start has progressed must be established. An engine relight occurs while the starter is energized, but until the engine rotor speed builds up close to the starter cutoff speed, the torque developed by the engine is not sufficient for self-sustained operation. The associated conditions can be expressed in Boolean algebra form:

$a_{53}\, b_7$ = air start required;
$a_{53}\, \bar{b}_7$ = ground start required;
$\bar{a}_{53}\, b_{10}$ = ground start still in progress; that is, relight achieved but starter still engaged; and
$\bar{a}_{53}\, \bar{b}_{10}$ = engine running under self-sustained power, where
a_{53} = engine flameout,
b_7 = terrain ground clearance greater than zero feet, and
b_{10} = starter energized.

The computational flow diagram is shown in Figure D-3.

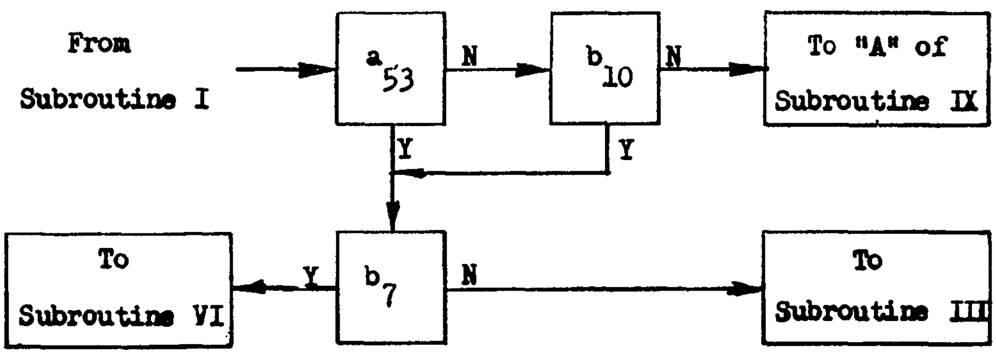

Figure D-3 - Subroutine II of Engine-Starting Routine

3. Subroutine III - Starter Energized?

The computational flow diagram for establishing whether or not the starter is energized is shown in Figure D-4. The diagram is self-explanatory except possibly for those aircraft in which a starter button or switch is not provided. In these aircraft the starter is energized by moving the throttle into the start detent on the throttle quadrant. Unless the throttle is moved to the start detent before it is moved to some other position on the quadrant, the starter "holding" solenoid will not be energized. This produces an indeterminant form when the throttle is neither in the "off" nor "start" positions. This indeterminant form is circumvented in the digital simulation by the use of b_{10}. The operations are defined below.

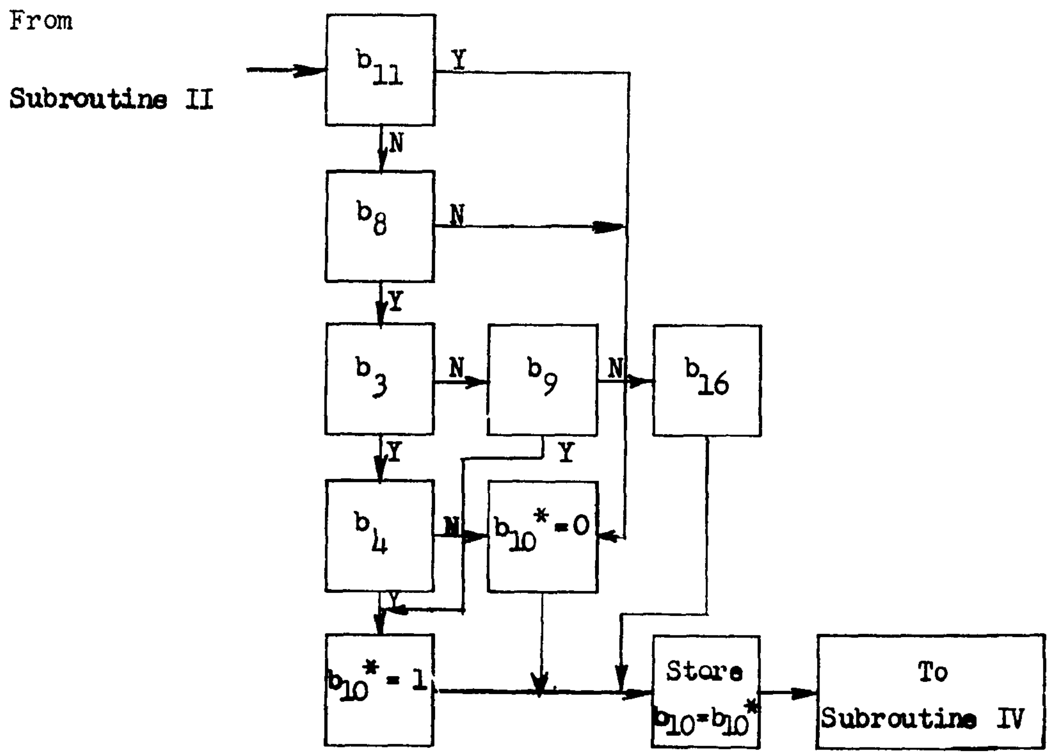

Figure D-4 - Subroutine III of Engine-Starting Routine

b_3 - Starter button or switch provided on aircraft.
b_4 - Starter button set to ON.
b_8 - GTC or APP power available for actuating starter.
b_9 - Throttle at START.
b_{10} - Starter energized.
b_{11} - $N > K_2$, where K_2 is the rpm of rotor at which starter automatically disengages.
b_{16} - Throttle set to OFF.

4. Subroutine IV - Computation of Starter Torque.

Regardless of the type of aircraft starter employed - pneumatic, air turbine, hot gas (combustion), etc. - the torque applied to the engine rotor through the starter drive can be expressed as a function of engine rotor speed. Of course, when the starter is not energized, the torque output with respect to the engine rotor is reduced to zero.

The computational flow diagram for Subroutine IV is shown in Figure D-5; the operations are defined below.

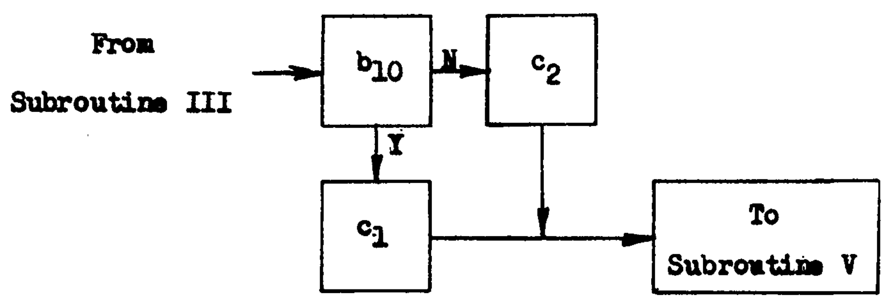

Figure D-5 - Subroutine IV for Computing Starter Torque

b_{10} - Starter energized.
c_1 - Compute and store $Q_{starter} = f_1(N)$.
c_2 - Store $Q_{starter} = 0$.

5. Subroutine V - Rotor Speed Within Limits Prescribed for Ground Start?

Flight handbooks stipulate a particular rotor speed at which to turn on the aircraft ignition while executing ground starts. This stipulation is to ensure that the ratio of engine air flow to engine fuel flow near the stipulated rotor speed is optimum for successful ground starts. A band of rotor speeds conducive to successful ground starts is provided for in the digital simulation. Unless the rotor speed falls within the preselected minimum and maximum rotor speed limits when the pilot turns on the ignition, all ground start attempts will result in failure. The computational flow diagram for determining whether the rotor speed is within these limits is shown in Figure D-6, and the operations are defined below.

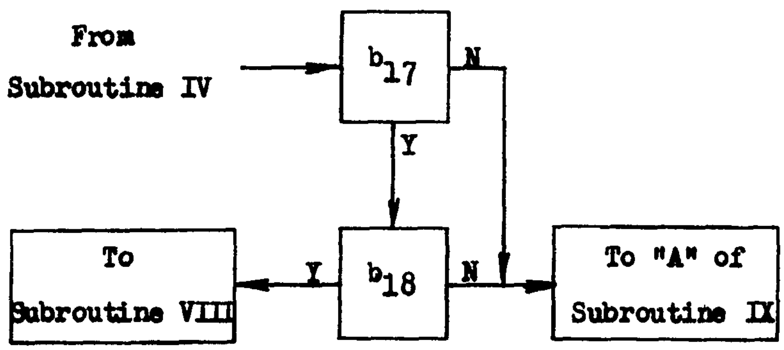

Figure D-6 - Subroutine V for Determining Rotor Speed

b_{17} - $N > K_3$, where K_3 is the minimum rotor speed at which an engine relight can be achieved during ground start attempts.

b_{18} - $N < K_4$, where K_4 is the maximum rotor speed at which an engine relight can be achieved during ground start attempts.

6. Subroutine VI - Electric Power Supplied to Engine Ignition (Air Starts)?

Air starts cannot be achieved unless electric power is supplied to the ignition system. Obviously, the GTC employed for ground start cannot be utilized; the power source must be internal to the aircraft. The digital routine shown in Figure D-7 will prevent an air start from being achieved for either of two reasons:

1. Electric power is not available for energizing the ignition system.
2. The ignition system is inoperative because the GTC is disconnected and the emergency procedure for "linking" the ignition system with an internal aircraft power source has not been executed by the pilot.

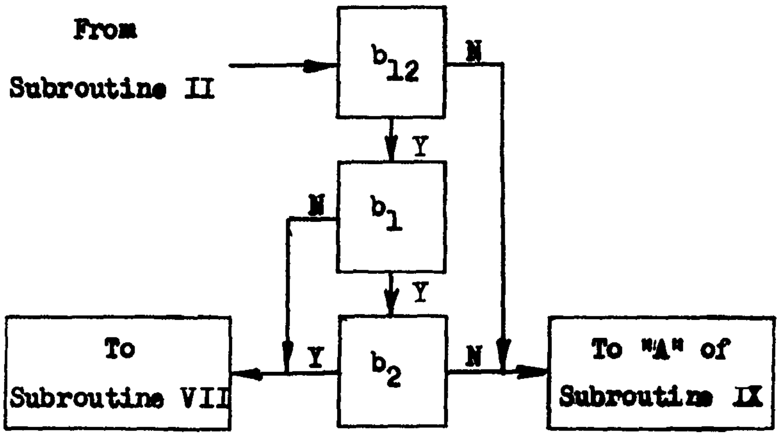

Figure D-7 - Subroutine VI to Ascertain Availability of Electric Power

The operations are defined below.

b_1 - Ignition system controlled by starter relay.
b_2 - Emergency ignition switch turned to ON.
b_{12} - Electric power, generated internal to the aircraft, is available for operating the ignition system.

7. Subroutine VII - Rotor Speed within Limits Prescribed for Air Start.

Subroutine VII is essentially the same as Subroutine V, except it applies to air starts rather than ground starts. Consequently, the rotor speed limits employed in the two subroutines are not necessarily the same. The computational flow diagram for Subroutine VII is given in Figure D-8, and the operations are defined below.

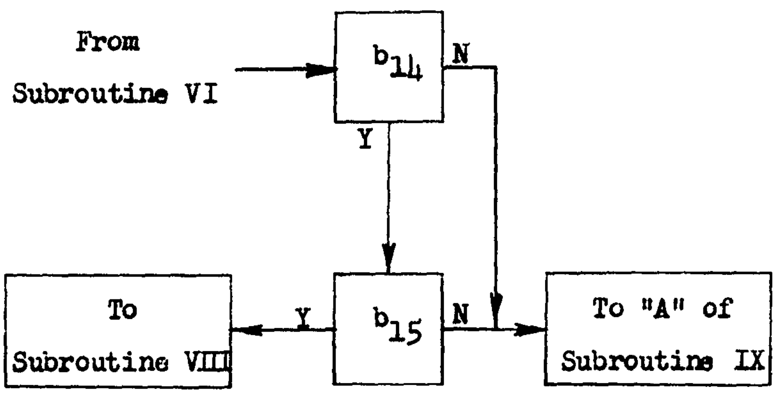

Figure D-8 - Subroutine VII to Ascertain Rotor Speed

b_{14} - $N > K_5$, where K_5 is the minimum rotor speed at which an engine relight can be achieved during air start attempts.

b_{15} - $N < K_6$, where K_6 is the maximum rotor speed at which an engine relight can be achieved during air start attempts.

8. Subroutine VIII - Ignition On?

As a result of the course of events leading up to Subroutine VIII, the ignitors within the engine combustion chambers will "fire" if:

1. The ignition system has not been failed by the instructor
2. The throttle is positioned other than in the "off" position
3. The ignition button, if provided, is held in the "on" position by the pilot

The computational flow diagram for Subroutine VIII is shown in Figure D-9, and the operations are defined below.

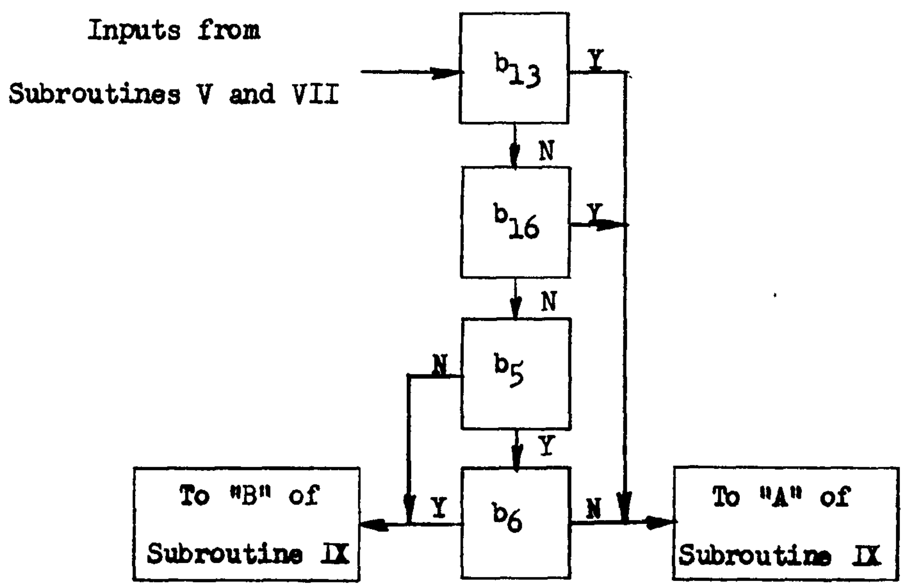

Figure D-9 - Subroutine VIII to Ascertain if Ignition Is On

b_{13} - Ignition system failed by instructor.
b_{16} - Throttle in off position.
b_5 - Ignition button provided on aircraft.
b_6 - Ignition button in on position.

9. Subroutine IX - Engine Relight Parameter.

In the simulation performed during Subroutine IX, it is intended that, once the engine has been shut down or the engine has flamed out, an engine relight can be obtained only if:

1. The engine is cleared of excess fuel before the ignition is turned "on"
2. The following events occur simultaneously:
   a. The engine speed is within the prescribed limits for an air or ground start
   b. The ignition is "on"
   c. The engine fuel flow is neither less than the minimum scheduled fuel flow limit nor greater than the maximum scheduled fuel flow limit

Except for item 2,c, above, which is determined in a subsequent subroutine, the above conditions can be true only when the computational flow of information leads from Subroutine VIII to "B" of Subroutine IX, and the value of b_{19} stored in Subroutine I indicates that the engine has been cleared of excess fuel.

The engine relight parameter, used in a later subroutine, denotes whether or not a relight will occur if the proper amount of fuel is supplied to the engine. The computational flow diagram for the generation of the relight parameter, b_{20}, is shown in Figure D-10. The operations are defined below.

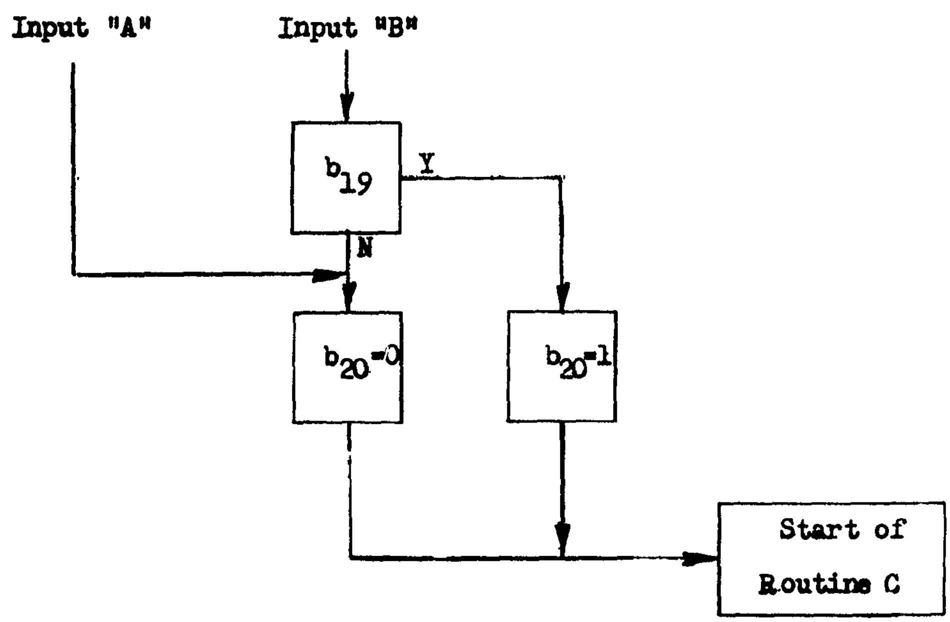

Figure D-10 - Subroutine IX for Engine Relight Parameter

b_{19} - Engine cleared of excess fuel
b_{20} - Relight occurs, provided the proper amount of fuel is supplied to the engine; b_{20} implies either that the engine is running or that a relight is impossible.

C. Oil Pressure Routine

In the digital simulation, engine oil pressure is generated as a function of engine speed. Provision is made for the instructor to effect either a total or partial pressure loss so that it appears to the pilot as if a malfunction of some form has occurred in the engine oil system. During such an occurrence, the engine speed function is multiplied by an appropriate constant. The computational flow diagram is shown in Figure D-11, and the operations are defined below.

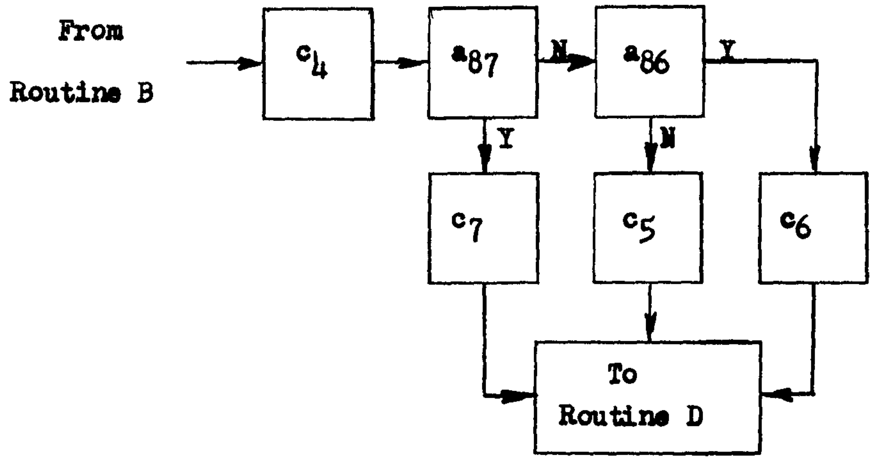

Figure D-11 - Oil Pressure Routine

c_4 - $P_{oil} = f_2(N)$
c_5 - $P_{oil} = P^*_{oil}$
c_6 - $P_{oil} = K_7 P^*_{oil}$, where $K_7 = \dfrac{(P_{oil})\text{ partial pressure loss}}{(P_{oil})\text{ normal operation}}$

c_7 - $P_{oil} = 0$
a_{86} - Oil system malfunction causing partial pressure loss, as instituted by instructor.
a_{87} - Total oil pressure loss instituted by instructor.

D. External Rotor Torque Routine.

Rotor torque as computed in this routine does not include the torque developed as a result of any thermodynamic reactions occurring in the engine. It refers only to externally and mechanically applied torque; that is, the torque developed by the engine starter, and the torque developed by a "binding" rotor. The total external rotor torque computed in this routine will, when added to the torques developed by the engine turbine and compressor, yield the total amount of torque applied to the engine rotor.

This simulation will permit the instructor to institute the effects of a binding engine rotor in conjunction with an oil system malfunction. During such an event, the rotor torque computed in this routine will be decreased appreciably so that the engine speed decreases to zero at a rapid rate. Thus, the engine tachometer and oil pressure indicator readings will indicate to the pilot that the engine malfunction occurred because of faulty engine lubrication.

The computational flow diagram for determining the total amount of external torque applied to the rotor is shown in Figure D-12, while the operations are defined below.

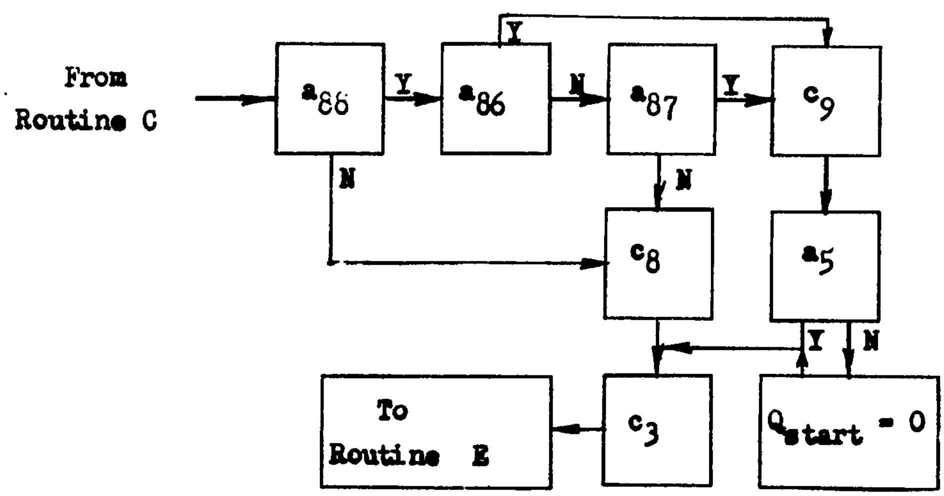

Figure D-12 - External Rotor Torque Routine

a_5 - Is start flag up?
a_{86} - Oil system malfunction causing partial pressure loss, as instituted by instructor.
a_{87} - Total oil pressure loss instituted by instructor.
a_{88} - Binding rotor effects desired by instructor.
c_3 - $Q_{total} = Q_{starter} + Q_{rotor\ bind}$.
c_8 - $Q_{rotor\ bind} = 0$
c_9 - $Q_{rotor\ bind} = -K_8$, where $-K_8$ is the rotor torque to be assumed for a binding rotor.

E. Fuel Available At Inputs To Engine And Afterburner Fuel Pumps? Store

Fuel is usually supplied to the engine from a single main supply tank. In some aircraft, however, twin supply tanks are provided, and fuel may be drawn from either or both of the tanks. Opening and closing the fuel tank shutoff valves determines from which tank(s) fuel is supplied. The shutoff valves, either mechanically or electrically operated, are usually controlled by a fuel selector switch located in the cockpit. In some instances where only a single main supply tank is employed, the fuel shutoff valve is controlled directly from the master switch. Fuel becomes available at the inputs to the engine and afterburner fuel pumps when there is fuel in at least one of the main supply tanks for which a fuel flow path has been opened, or if the system has a by-pass delivery mode and if that mode is in use. Thus, there are five possible combinations of delivery modes:

1. A single tank serving a single engine (or a set of two engines)
2. Two tanks serving a single engine
3. A single tank serving two engines (or two sets)
4. Two tanks serving two engines
5. By-pass mode

The delivery mode in use and the condition of the flow paths must be ascertained. In addition, the available flow rate to the engine fuel pumps must be determined. The following conditions must be observed in the interest of computational efficiency.

1. The by-pass mode is used only when the service tank shutoff valves are closed, and it cannot be used with the cross-feed option.
2. If a service tank is operating in a gravity mode, it cannot be cross-fed to a pressurized fuel line.

The digital routine used to determine that fuel is available at the engine fuel pumps is shown in the routine of Figure D-13. The subroutines are shown in Figures D-14 and D-15, and the operations are defined below.

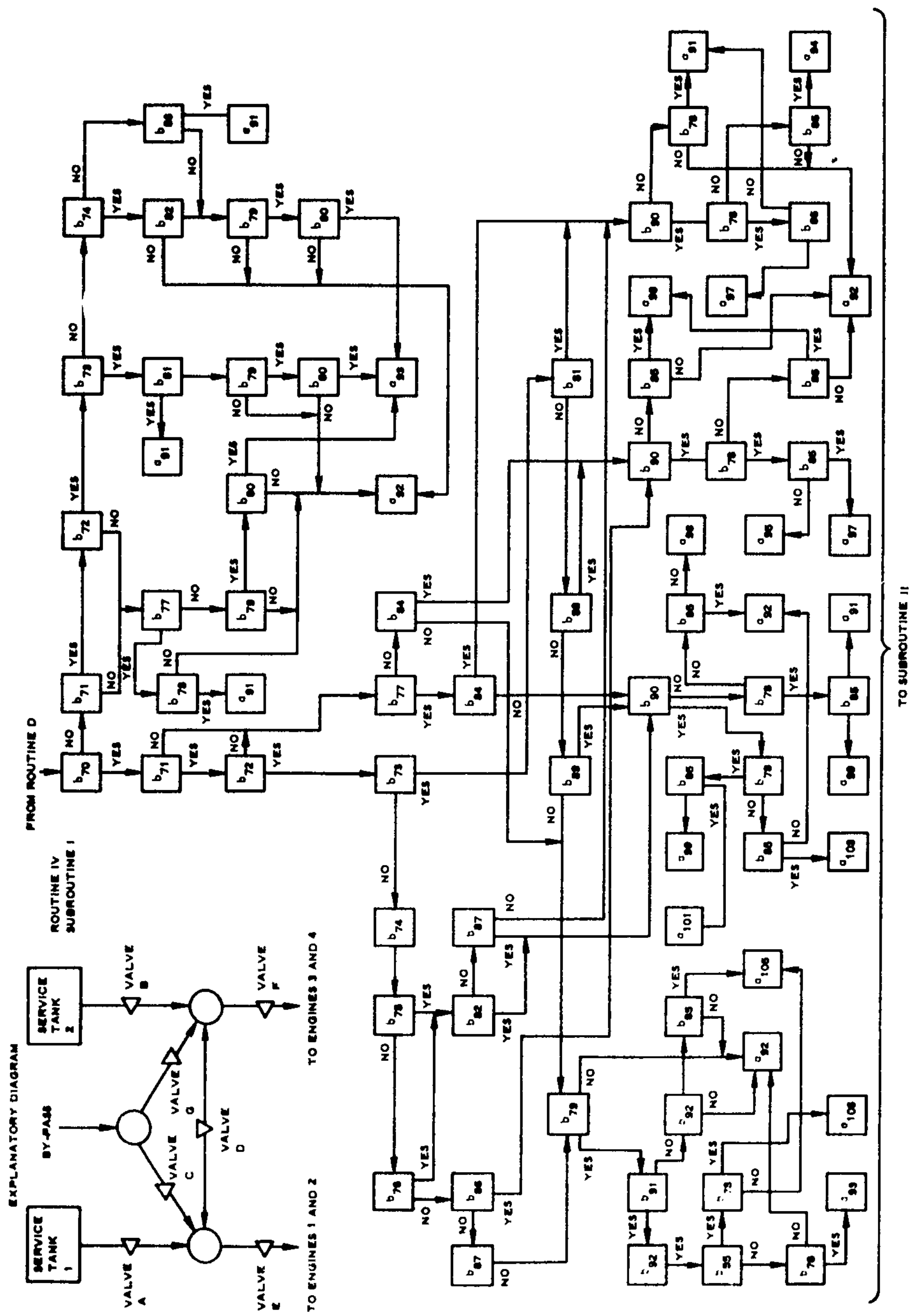

Figure D-13 - Fuel Available Routine

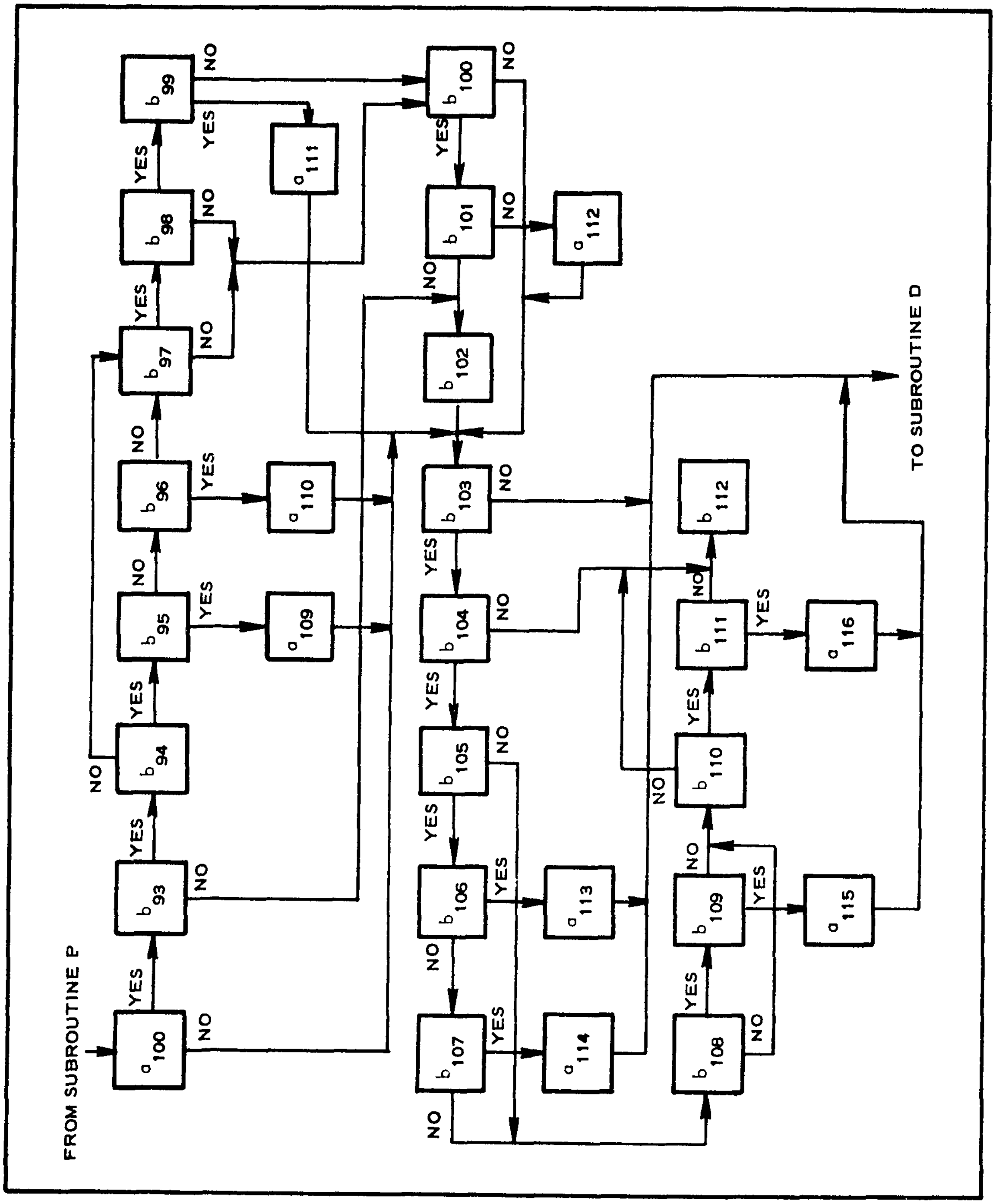

Figure D-14 - Subroutine II of Fuel Available Routine

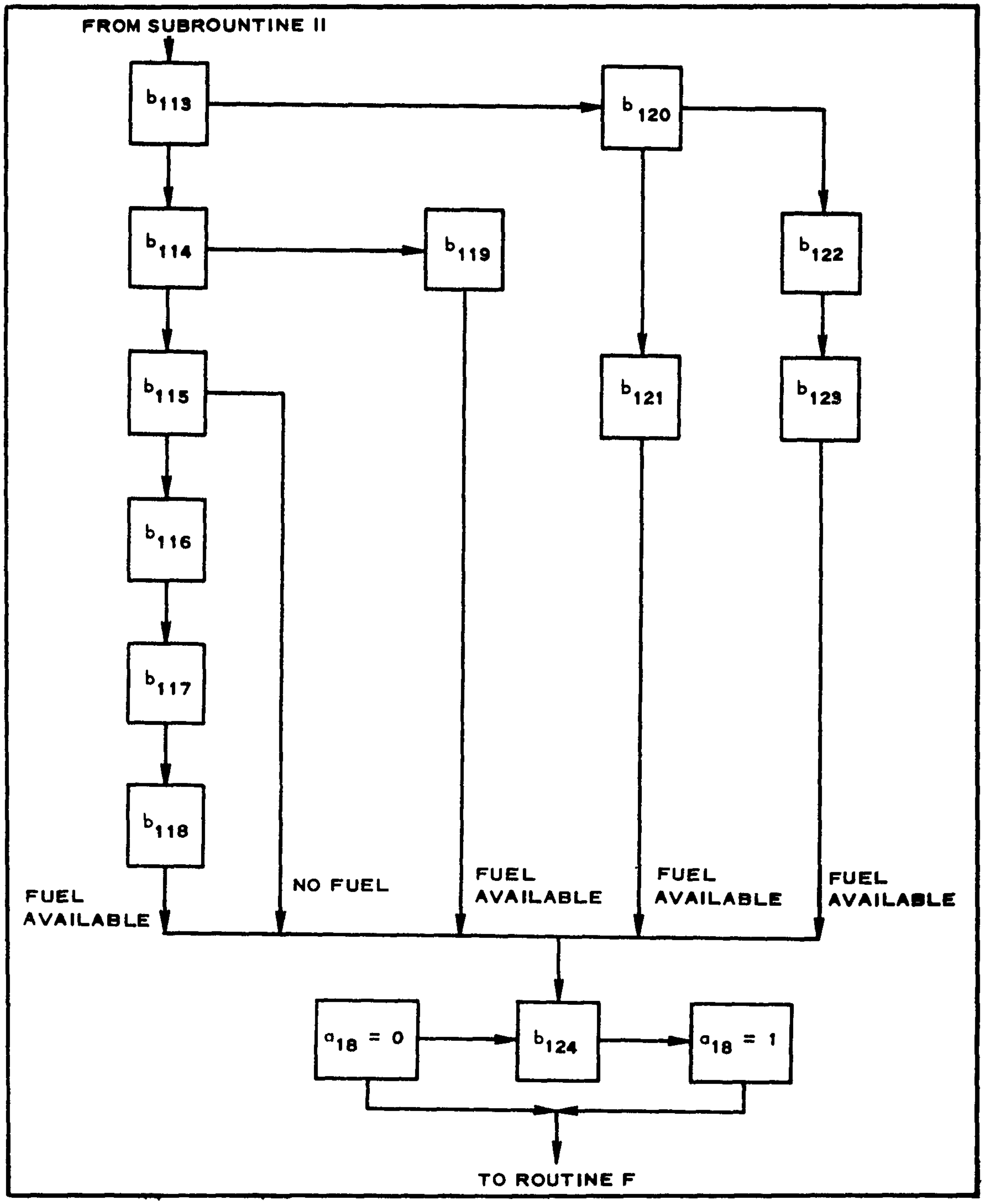

Figure D-15 - Subroutine III of Fuel Available Routine

a_{18} - Fuel is available at engine fuel pumps.
a_{91} - Store fuel flow path as AE; go to a_{100}.
a_{92} - Store "no fuel flow;" go to a_{100}.
a_{93} - Store fuel flow path as CE; go to a_{100}.
a_{94} - Store fuel flow path as UDF; go to a_{100}.
a_{95} - Store fuel flow path as BDE; go to a_{100}.
a_{96} - Store fuel flow path as BF + BDE; go to a_{100}.
a_{97} - Store fuel flow path as AE + ADF.
a_{98} - Store fuel flow path as BF.
a_{99} - Store fuel flow path as AE + BF.
a_{100} - Is tank 1 selected to supply fuel?
a_{101} - Store fuel flow path as AE + BDF.
a_{102} - Store fuel flow path as AF + BF + ADF + BDE.
a_{103} - Store fuel flow path as BF + ADF.
a_{105} - Store fuel flow path as GF.
a_{106} - Store fuel flow path as GF + CE.
a_{109} - Use double pump element transfer function for flow leaving tank 1.
a_{110} - Use single pump element transfer function for flow leaving tank 1.
a_{111} - Use emergency low-speed transfer function for flow leaving tank 1.
a_{112} - Use gravity-flow transfer function for flow leaving tank 1.
a_{113} - Use double-pump element transfer function for flow leaving tank 2.
a_{114} - Use single-pump element transfer function for flow leaving tank 2.
a_{115} - Use low-speed element transfer function for flow leaving tank 2.
a_{116} - Use gravity-flow transfer function for flow leaving tank 2.
b_{70} - Are there two service tanks?
b_{71} - Are the shutoff valves electrically operated?
b_{72} - Is shutoff valve power available?
b_{73} - Is there a service tank selector switch?
b_{74} - Store, shutoff valves controlled by engine master switch.
b_{75} - Is engine master 1 on?
b_{76} - Is engine master 2 on?
b_{77} - Is shutoff valve A open?
b_{78} - Is shutoff valve E open?
b_{79} - Is there a by-pass mode?
b_{80} - Is by-pass mode is use?
b_{81} - Is selector switch in A?

b_{82} - Engine master switch on.
b_{83} - Is shutoff valve open?
b_{84} - Is shutoff valve B open?
b_{85} - Is shutoff valve F open?
b_{86} - Is engine master 3 on?
b_{87} - Is engine master 4 on?
b_{88} - Is selector switch in B?
b_{89} - Is selector switch in both?
b_{90} - Is cross-feed valve D open?
b_{91} - Is by-pass valve C open?
b_{92} - Is by-pass valve G open?
b_{93} - Does tank 1 contain fuel?
b_{94} - Is high-speed boost pump power available?
b_{95} - Are both high-speed pump elements operative?
b_{96} - Is one high-speed boost pump element operative?
b_{97} - Is emergency low-speed power available?
b_{98} - Is emergency low-speed pump operative?
b_{99} - Is emergency low-speed mode in use?
b_{100} - Is there a gravity mode available?
b_{101} - Is g vector positive?
b_{102} - Store: no fuel leaving tank 1.
b_{103} - Is tank 2 selected to supply fuel?
b_{104} - Does tank 2 contain fuel?
b_{105} - Is high-speed pump power available?
b_{106} - Are both high-speed pump elements operative?
b_{107} - Is one high-speed pump element operative?
b_{108} - Is emergency low-speed power available?
b_{109} - Is emergency low-speed pump in use?
b_{110} - Is there a gravity mode available?
b_{111} - Is g vector positive?
b_{112} - Store: no fuel leaving tank 2.
b_{113} - Is fuel leaving tank 1?
b_{114} - Is fuel leaving tank 2?
b_{115} - Is the by-pass mode in use?
b_{116} - Is the by-pass mode selected to supply fuel?
b_{117} - Is there fuel in at least one tank supplying the by-pass line?
b_{118} - Store: use the by-pass transfer function for fuel flow.
b_{119} - Store: use the transfer function stored previously for tank 2.
b_{120} - Is fuel flowing from tank 2?
b_{121} - Store: use the transfer function stored previously for tank 1.
b_{122} - Combine the stored transfer functions for tanks 1 and 2.
b_{123} - Store the combined transfer functions for fuel flow.
b_{124} - Is fuel available at the inputs to the engine fuel pumps.

F. Compute and Store Effective Fuel Pressure.

The fuel flow capable of being delivered by the main engine and afterburner fuel pumps normally exceeds the fuel demands established by the main engine and afterburner fuel control units. However, fuel-tank booster pump failures can reduce the flow rate output of the engine and afterburner fuel pumps below the output demanded for normal engine and afterburner operation; and an empty fuel-supply tank selected by reason of pilot error will result in stopping the flow of fuel entirely. It is necessary to establish the effective fuel pressure, P_{reg}, being maintained, with respect to the engine and afterburner fuel control units, so that the maximum flow rate available can be ascertained. In a later subroutine, the available and demanded flow rates are compared to establish the actual rate at which fuel is being metered to the fuel nozzles and afterburner spray bars. The computational flow diagram for determining the effective fuel pressure is shown in Figure D-16.

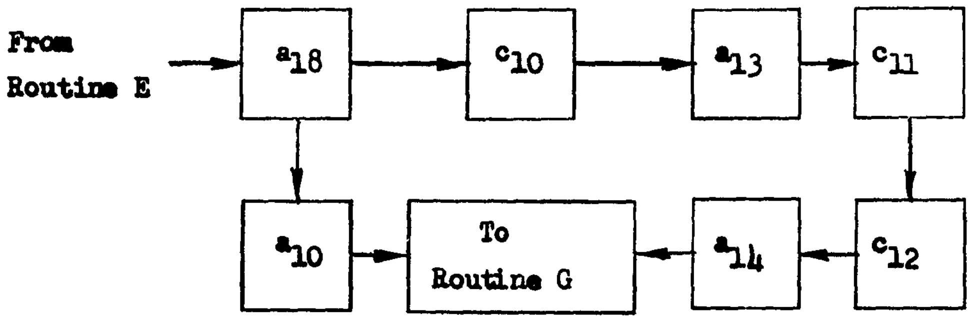

Figure D-16 - Effective Fuel Pressure Routine

a_{10} - Set $P_{eff} = 0$.
a_{13} - Store combined engine fuel transfer function.
a_{14} - Store P_{eff}.
a_{18} - Fuel is available at engine fuel pump.
c_{10} - Combine the engine transfer function from Routine E with the engine fuel pump transfer function.
c_{11} - Use $W_{f(n-1)}$ to compute P_s from the combined engine transfer function.
c_{12} - Compute $P_{eff} = \frac{P_{reg}}{P_s}$.

G. Emergency Afterburner Modulation System On? Store.

Some aircraft are equipped with an emergency afterburner modulation system that permits afterburner light-off in the military sector of the throttle quadrant and allows modulation to landing power range. This emergency feature is provided when the normal thrust output of the engine is not sufficient to maintain flight in the landing configuration when or if the jet nozzle fails in the open position.

When the emergency modulation system is turned "on," the afterburner demand switch is electrically by-passed; the acceleration bleed valves are de-energized in the open position; the inlet guide vanes are de-energized in the closed position; the exhaust nozzle override is energized, causing the nozzle to open if it is not already fully open; the normal fuel schedule for the afterburner is modified to prevent a lean mixture blowout at decreased throttle settings; and the normal fuel schedule for the engine is modified to prevent stagnation at decreased engine speeds. The necessity for establishing whether or not the emergency afterburner modulation system is in use is obvious; the computational flow diagram is shown in Figure D-17 and the operations are defined below.

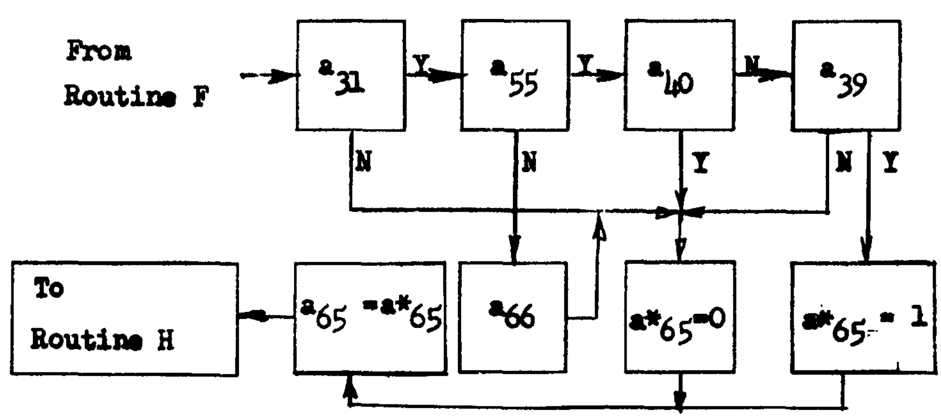

Figure D-17 - Emergency Afterburner Modulation System Routine

a_{31} - Engine equipped with an emergency afterburner modulation system.
a_{39} - Emergency afterburner modulation switch in ON position.
a_{40} - Emergency afterburner modulation system failed by instructor.
a_{55} - Electric power available for operating afterburner fuel control system.
a_{65} - Emergency afterburner modulation system is in operation.
a_{66} - Emergency modulation system is deactivated by electrical power failure.

H. Fuel Available at Input to Main Engine Fuel Control Unit? Store.

Depending on the particular aircraft, fuel to the main engine fuel control system is supplied from either a dual-stage engine-driven fuel pump or from two engine-driven fuel pumps operating in parallel. This duplication ensures that adequate fuel will be supplied to the engine in case a fuel pump fails. For the dual-stage engine-driven fuel pump, the emergency stage is normally employed to supply fuel to the afterburner fuel control unit. When the main engine stage fails, the flow of fuel from the emergency afterburner stage to the afterburner fuel control unit is reduced until an adequate supply of fuel is being by-passed to the main engine fuel control unit. This changeover is accomplished automatically.

The routine for determining whether fuel is available at the input to the main engine fuel control unit is shown in Figure D-18. The routine for establishing whether or not fuel is available at the inputs to the engine-driven fuel pumps was discussed in item E, above. The operations involved in this routine are defined below.

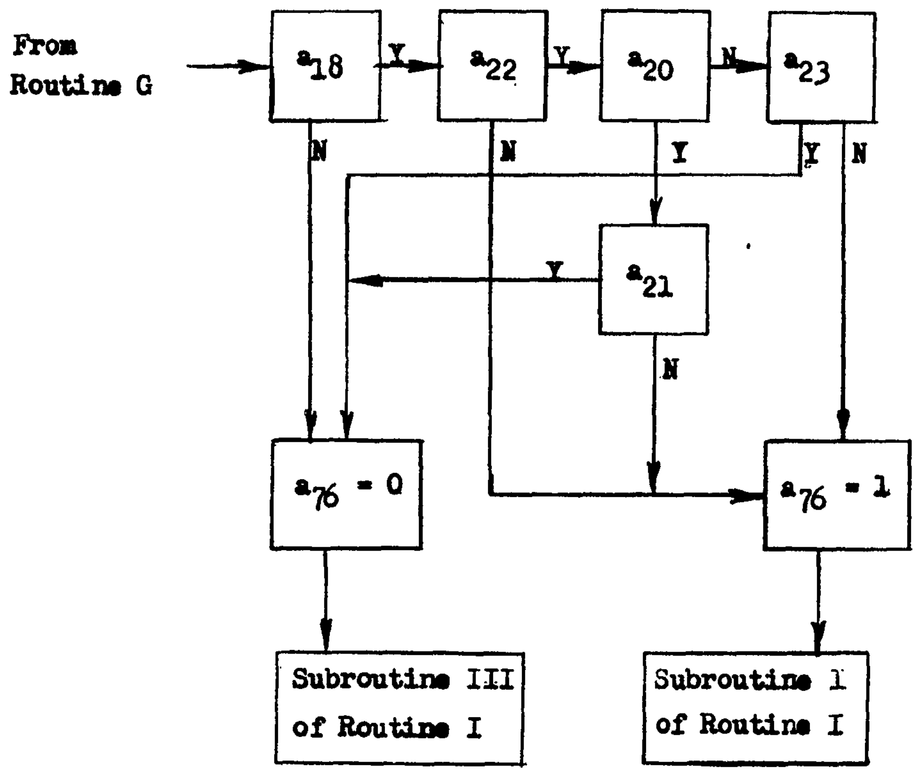

Figure D-18 - Routine for Fuel Availability at Input to Main Engine Control Unit

a_{18} - Fuel available at inlets to engine and afterburner fuel pumps.

a_{20} - Afterburner fuel pump is separate from engine emergency fuel pump.

a_{21} - Failure of afterburner fuel pump (or afterburner stage) by instructor.

a_{22} - Failure of engine fuel pump no. 1 (or engine stage) by instructor.

a_{23} - Failure of engine fuel pump no. 2 by instructor.

a_{76} - Fuel available at input to main engine fuel control unit.

I. Engine Fuel Flow Routine.

From the engine-driven fuel pumps, fuel is pumped to the main fuel-control unit where it is metered in the proper quantities to the fuel nozzles of the engine combustor. The main fuel control unit can be viewed as having a fuel-metering system and a computing system that together control engine fuel flow during engine starting, acceleration, deceleration, and steady-state operation. The metering system selects fuel flow to be supplied to the engine burners in accordance with the amount of thrust demanded by the particular throttle position selected by the pilot; but this flow rate is subject to engine operating limitations scheduled by the computing system as it monitors various operating parameters: compressor-inlet temperature, compressor-inlet pressure, compressor-discharge pressure, and burner pressure. The computing system safe-guard against compressor stall, flameout, engine overspeed, and pressures and temperatures that exceed the mechanical limits of the engine.

In case the normal control system malfunctions, main engine fuel flow control can be transferred to the emergency fuel control system, assuming that one is provided, by manually operating a switch in the cockpit. During emergency operation of the fuel control unit, the normal compensation of fuel flow is eliminated, and the pilot must control fuel flow manually with the throttle. Emergency flow is altitude-compensated up to approximately 30,000 ft. Above this altitude the pilot must manipulate the throttle to maintain constant rpm; the throttle must be moved slowly and smoothly to prevent compressor stall during acceleration and a flameout during deceleration.

Actual engine fuel flow depends not only upon the fuel flow demand established by the engine fuel control unit, either normal or emergency, but also up on the amount of fuel flow that can be delivered by the engine-driven fuel pumps. That is, during a malfunction that affects fuel pump delivery, the maximum rate at which fuel can be delivered to the engine may not be sufficient to meet the demand established by the fuel control unit. In the digital simulation, demanded and available rates of flow are compared to establish the actual rate at which fuel is being supplied to the engine burners.

The computation flow diagram used in the proposed digital simulation is shown in Figure D-19; the individual subroutines are discussed below.

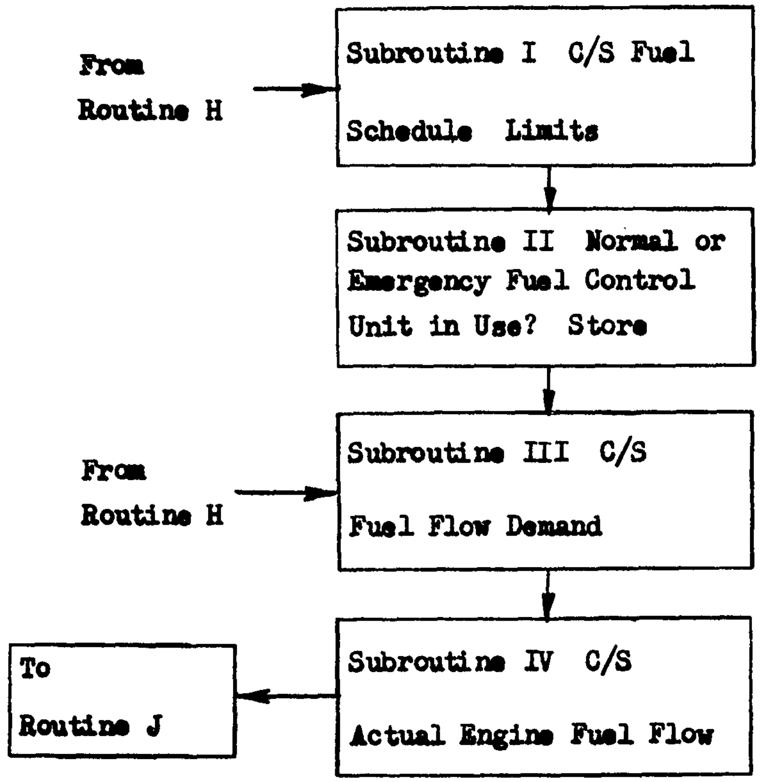

Figure D-19 - Engine Fuel Flow Routine

1. Subroutine I - Compute and Store Fuel Schedule Limits

From a consideration of the main fuel control unit described above, the fuel schedule limits can be designated to form a part of the fuel control unit computing system. The minimum limit essentially ensures that enough fuel will be supplied to the engine to prevent a lean fuel air mixture flameout. The maximum limit prevents excessive amounts of fuel from being supplied to the engine burners, thereby protecting against compressor stall and rich flameout. The fuel schedule limits are varied with the engine operating parameters mentioned earlier. Since these parameters are not monitored when the emergency fuel control unit is in operation, protection from compressor stall and flameout is furnished by the use of the normal fuel control unit only.

The computational flow diagram used in the digital simulation is shown in Figure D-20. Note that entry into this routine occurs only when it is established in Routine H that fuel is available at the outputs of the engine-driven fuel pumps. The operations are defined below.

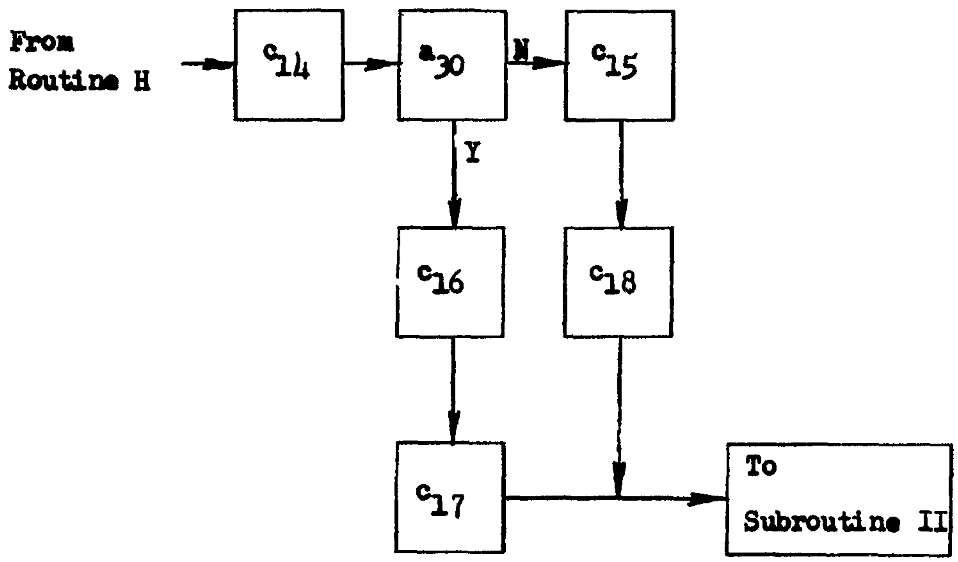

Figure D-20 - Subroutine I for Fuel Schedule Limits

a_{30} - Either compressor-discharge pressure of burner pressure is used in establishing the maximum and minimum limits for fuel flow to the engine.

c_{14} - $\dfrac{W_{f_{max}}}{P_x} = f_1 \, (N, T_2)$ (see Note, below).

c_{15} - $\dfrac{W_{f_{max}}}{P_2} = \dfrac{W_{f_{max}}}{P_x}.$

c_{16} - $\dfrac{W_{f_{max}}}{P_2} = \dfrac{W_{f_{max}}}{P_x} \times \dfrac{P_3}{P_2}$

$$c_{17} - \frac{W_{f_{min}}}{P_2} = f_1 \frac{P_3}{P_2} .$$

$$c_{18} - \frac{W_{f_{min}}}{P_2} = f_3 \,(N) .$$

NOTE

Depending on the particular aircraft, P_x will be identical to one of the following parameters: compressor inlet pressure, compressor discharge pressure, or burner pressure. However, the digital simulation includes provisions for using the burner pressure parameter directly. It is intended that $f(N, T_2)$ be modified to permit the substitution of P_3 for P_x in lieu of P_B, thereby eliminating the need to use, and hence the requirement to generate, the burner pressure parameter in the engine simulation.

2. Subroutine II - Normal or Emergency Fuel Control Unit in Use? Store.

The computational flow diagram, shown in Figure D-21, determines whether the normal or the emergency fuel control unit is being used to continue engine fuel flow. The operations are defined below.

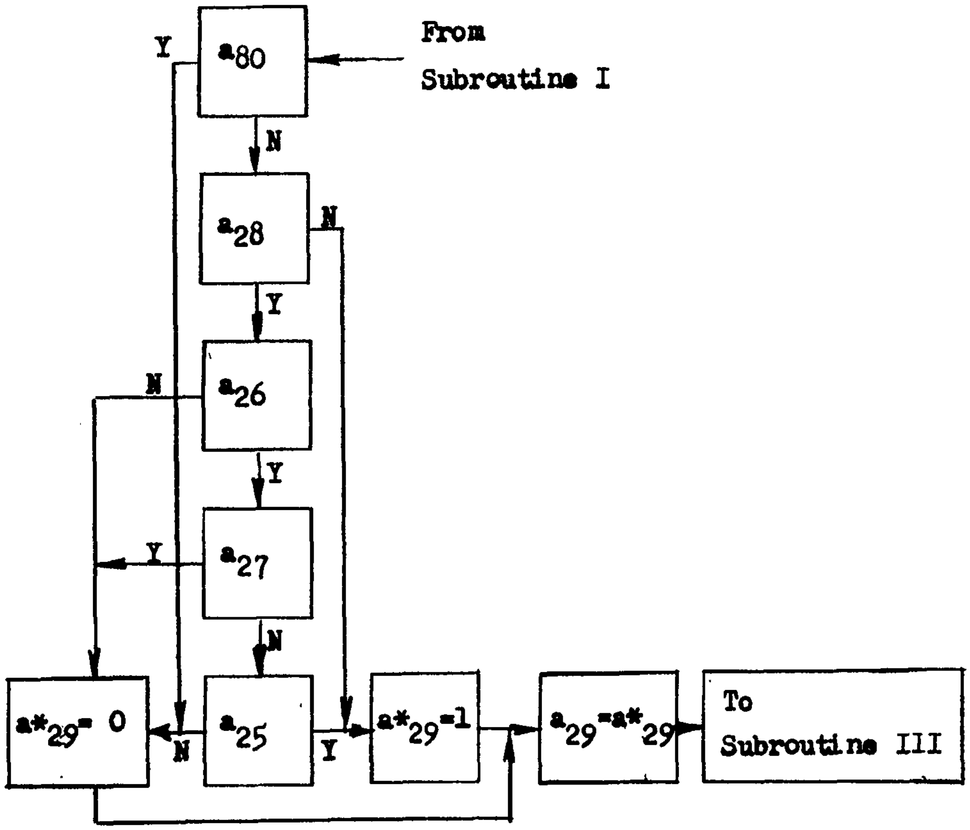

Figure D-21 - Subroutine II to Ascertain Fuel Control Unit in Use

a_{25} - Emergency fuel control selector switch in "normal," not "emergency," position.

a_{26} - Electric power available for accomplishing a change-over from normal to emergency fuel control operation, or vice versa.

a_{27} - Emergency fuel control system actuator (normal to emergency control, or vice versa) failed by instructor.

a_{28} - Emergency fuel control system provided for engine.

a_{29} - Normal fuel control unit being used to control engine fuel flow.

a_{80} - Speed governor failed by instructor (this type of failure is applicable only to the normal fuel control unit; switching to the emergency fuel control unit routine yields the desired effects).

3. Subroutine III - Compute and Store Fuel Flow Demand.

The main fuel control unit is essentially an isochronous control in which an integrated speed error signal positions a fuel-metering valve. The speed error signal is obtained by comparing engine speed (rotor rpm) with an engine speed demand established as a function of throttle position and compressor inlet temperature. The fuel flow limits mentioned in Subroutine I are incorporated into the control by restricting the minimum and maximum opening of the fuel-metering valve. Further limiting of fuel flow is provided by the action of a speed governor during engine accelerations. The governor eliminates excessive overspeeds by reducing fuel flow below the maximum scheduled limit as the engine speed approaches or overshoots the maximum rated engine speed.

During emergency operation the fuel metering valve is positioned essentially by direct mechanical linkage with the throttle; that is, speed error compensation, speed governor action, fuel-flow limiter action, and temperature compensation are eliminated. Some altitude compensation, however, is provided by monitoring compressor inlet pressure.

The digital simulation shown in Figure D-22 applies to both modes of operation. Note that provisions have been made for the instructor to introduce malfunctions in both the emergency and normal fuel control units. In addition, the fuel demand established for normal operation is modified by operation of the emergency afterburner modulation system; the necessary changes in fuel flow are introduced into the simulation when the pilot energizes the emergency afterburner modulation system. The operations are described below.

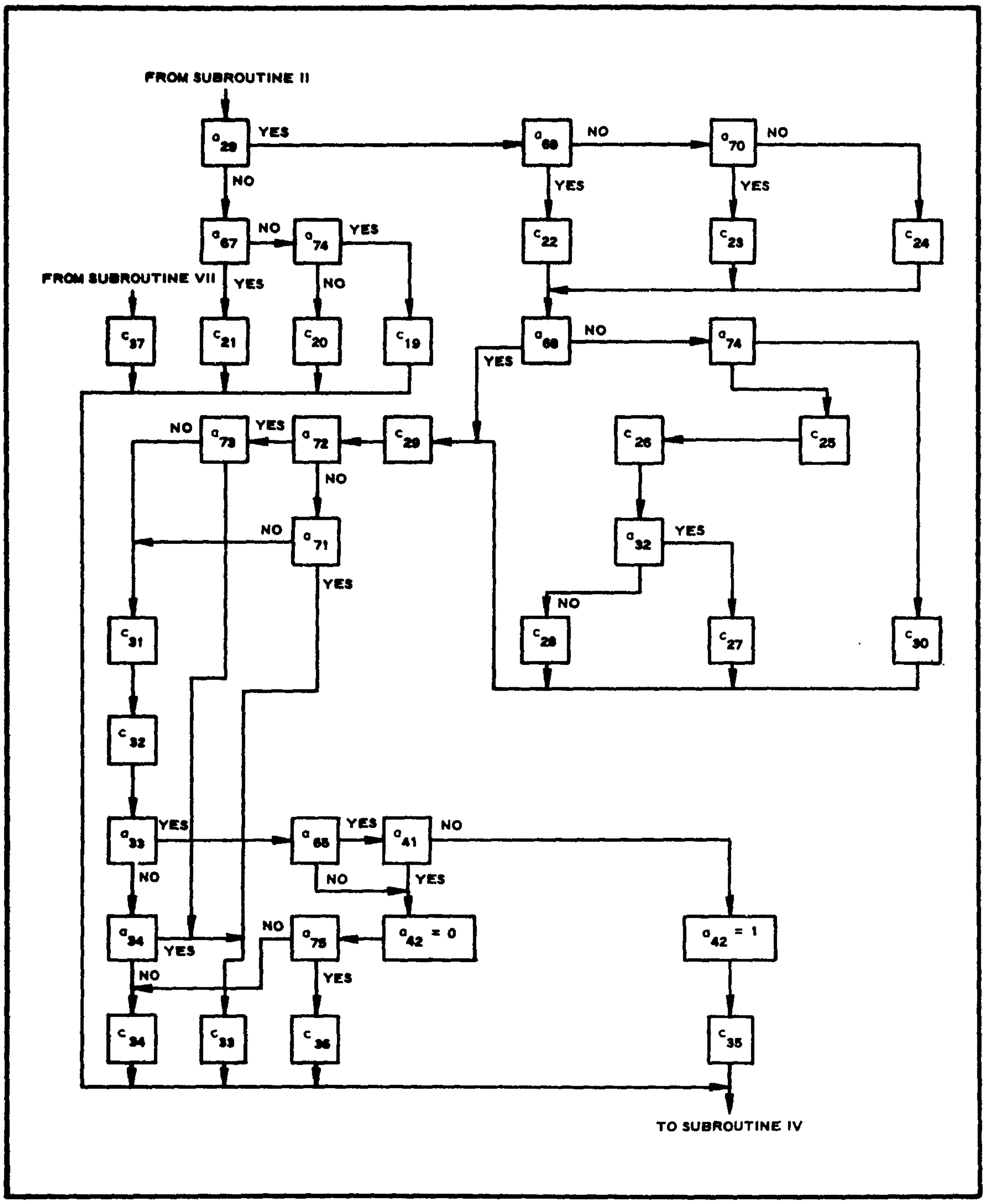

Figure D-22 - Subroutine III to Compute and Store Fuel Flow Demand

c_{19} - $\frac{W_f^{**}}{P_2}$ = K_9, where K_9 is the fuel flow obtained when a throttle linkage failure occurs, assuming a fixed position of the fuel-metering valve in the emergency fuel control unit.

c_{20} - $\frac{W_f^{**}}{P_2}$ = $f_1\ (\alpha)$.

c_{21} - $\frac{W_f}{P_2}$ = 0.

c_{22} - μ = K_{10}, where K_{10} is fuel control gain suitable for effecting slow throttle response.

c_{23} - μ = K_{11}, where K_{11} is fuel control gain suitable for effecting desired degree of engine instability.

c_{24} - μ = K_{12}, where K_{12} is fuel control gain during normal operation.

c_{25} - N_D^* = f_2.

c_{26} - N_{Dmax} = $f_1\ (T_2)$.

c_{27} - N_D = N_{Dmax} .

c_{28} - N_D = N_D^*.

c_{29} - N_E = $N_D - N$.

c_{30} - N_D = K_{13}, where K_{13} is the speed demand when a throttle linkage failure occurs; a fixed position of fuel control unit throttle linkage is assumed.

c_{31} - $\frac{\Delta W_f^*}{P_2}$ = $N_E\ \Delta t$.

c_{32} - $\frac{W_f^*}{P_2} = \frac{W_f}{P_2} + \frac{\Delta W_f^*}{P_2}$.

c_{33} - $\frac{W_f^{**}}{P_2} = \frac{W_{f_{min}}}{P_2}$.

c_{34} - $\frac{W_f^{**}}{P_2} = \frac{W_f^*}{P_2}$.

c_{35} - $\frac{W_f^{**}}{P_2} = \frac{W_{f_{max}}}{P_2}$.

c_{36} - $\frac{W_f^{**}}{P_2} = K_{14} \frac{W_{f_{max}}}{P_2}$, $K_{14} = W_{f(a42 = 0)}/W_{f(a42 = 1)}$.

c_{37} - $\frac{W_f^{**}}{P_2} = 0$.

a_{29} - Normal fuel control unit is being used to control engine fuel flow.

a_{32} - $N_D^* > N_{D_{max}}$.

a_{33} - $\frac{W_f}{P_2} > \frac{W_{f_{max}}}{P_2}$.

a_{34} - $\frac{W_f}{P_2} < \frac{W_{f_{min}}}{P_2}$.

a_{41} - Engine speed greater than fuel enrichment solenoid cutoff, $N > N_{FE}$.

a_{42} - Fuel enrichment solenoid valve closed.

a_{65} - Emergency afterburner modulation system is in operation.

a_{67} - Emergency fuel control unit failed by instructor.

a_{68} - No change in fuel flow with throttle changes (instructor).

a_{69} - Malfunction of engine fuel control unit: slow throttle response (instructor).

a_{70} - Malfunction of engine fuel control unit: unstable engine operation (instructor).

a_{71} - $N > 101$ percent , where N_{max} is maximum rated rotor speed.

a_{72} - Engine overspeed requested by instructor.

a_{73} - $N > N_{overspeed}$, where $N_{overspeed}$ is any desired constant that is suitable for use when $a_{72} = 1$.

a_{74} - Broken throttle linkage (instructor).

a_{75} - $\frac{W_f}{P_2} > K_{14} \frac{W_{f_{max}}}{P_2}$, where $K_{14} = \frac{W_{f(a42 = 0)}}{W_{f(a42 = 1)}}$.

4. Subroutine IV - Compute and Store Actual Engine Fuel Flow.

In Subroutine IV the fuel available from the engine-driven fuel pumps is computed and compared with the fuel demand established in Subroutine III. The actual rate at which fuel is being supplied to the engine burners is then obtained. The computational flow diagram is presented in Figure D-23; the operations are defined below.

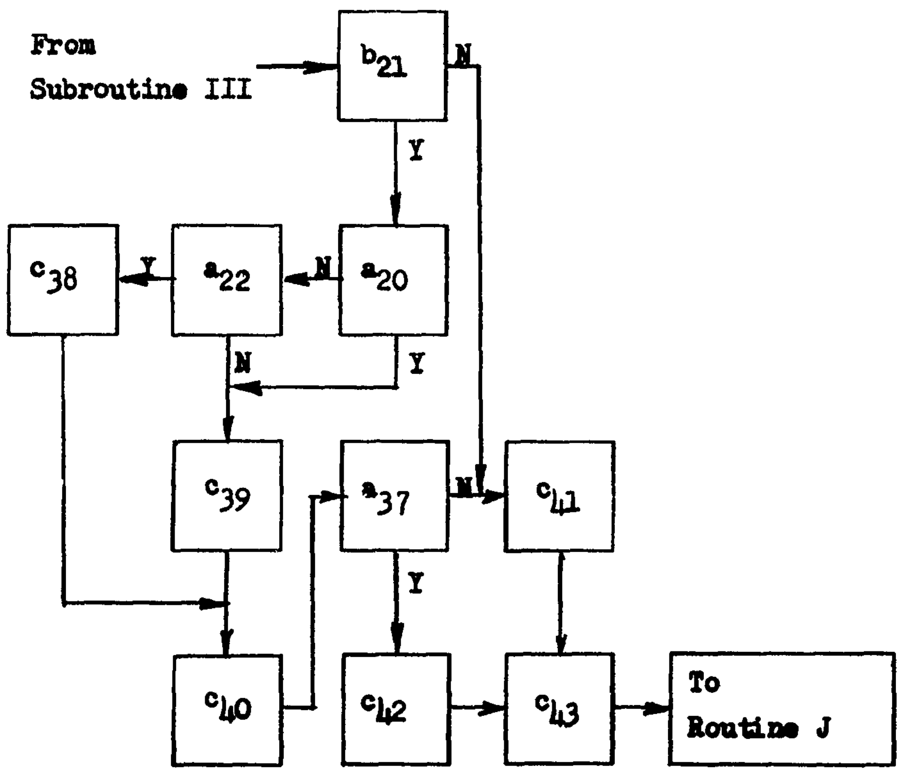

Figure D-23 - Subroutine IV for Computing Engine Fuel Flow

a_{20} - Afterburner fuel pumps are separate from engine emergency fuel pump.

a_{22} - Failure of engine fuel pump no. 1 (or engine stage) by instructor.

a_{37} - $\dfrac{W_{f_{avail}}}{P_2} \leq \dfrac{W_f}{P_2}$

b_{21} - $P_{eff} < 1$

c_{38} - $W_{f_{avail}} = f_1 (P_{eff})$ (single-element engine fuel pump transfer function).

c_{39} - $W_{f_{avail}} = f_2 (P_{eff})$ (double-element engine fuel pump transfer function).

c_{40} - $\dfrac{W_{f_{avail}}}{P_2} = W_{f_{avail}} \left[\dfrac{1}{P_2}\right]$

c_{41} - $\dfrac{W_f}{P_2} = \dfrac{W_f^{**}}{P_2}$.

c_{42} - $\dfrac{W_f}{P_2} = \dfrac{W_{f_{avail}}}{P_2}$.

c_{43} - $W_f = \left[\dfrac{W_f}{P_2}\right]^{\dagger} P_2$.

J. Compressor Stall and Flameout Routine.

A prime purpose of the maximum fuel flow limit [see Subroutine I of Routine I (item I, 1, above)] is to safeguard against compressor stall and rich flameout. Likewise, the minimum fuel limit essentially eliminates lean flameouts. Although the actual conditions that result in flameout or compressor stall are determined by the thermodynamic relationships existing in the engine, it is sufficient for simulator purposes to assume that the conditions for compressor stall and rich flameout are satisfied when engine fuel flow has reached or exceeded the maximum fuel limit, and that the conditions for a lean flameout are satisfied when engine fuel flow has decreased to or below the minimum fuel limit.

The effects of a compressor stall or flameout upon the dependent engine parameters - temperatures, pressures, air flow, and gross thrust-are not treated here since they form a part of the engine simulation. This routine simply provides a signal to indicate when the effects of a compressor stall or flameout should be simulated in the engine simulation (see Appendix E).

A signal to simulate the effects of flameout occurs when:

1. Engine fuel flow exceeds the maximum limit by a prescribed percentage
2. Engine fuel flow falls below the minimum limit by a prescribed percentage
3. A rich or lean flameout is requested by the instructor and engine fuel is at or above the maximum limit, or at or below the minimum limit, respectively.

A signal to simulate the effects of compressor stall results when engine fuel flow is at or above the maximum fuel limit and a compressor stall is requested by the instructor. In the event the instructor has requested both compressor stall and rich flameout, the request for a flameout predominates.

The computational flow diagram for the compressor stall and flameout routine is shown in Figure D-24. Note the use of the relight parameter generated in the starting routine. The operations are defined below.

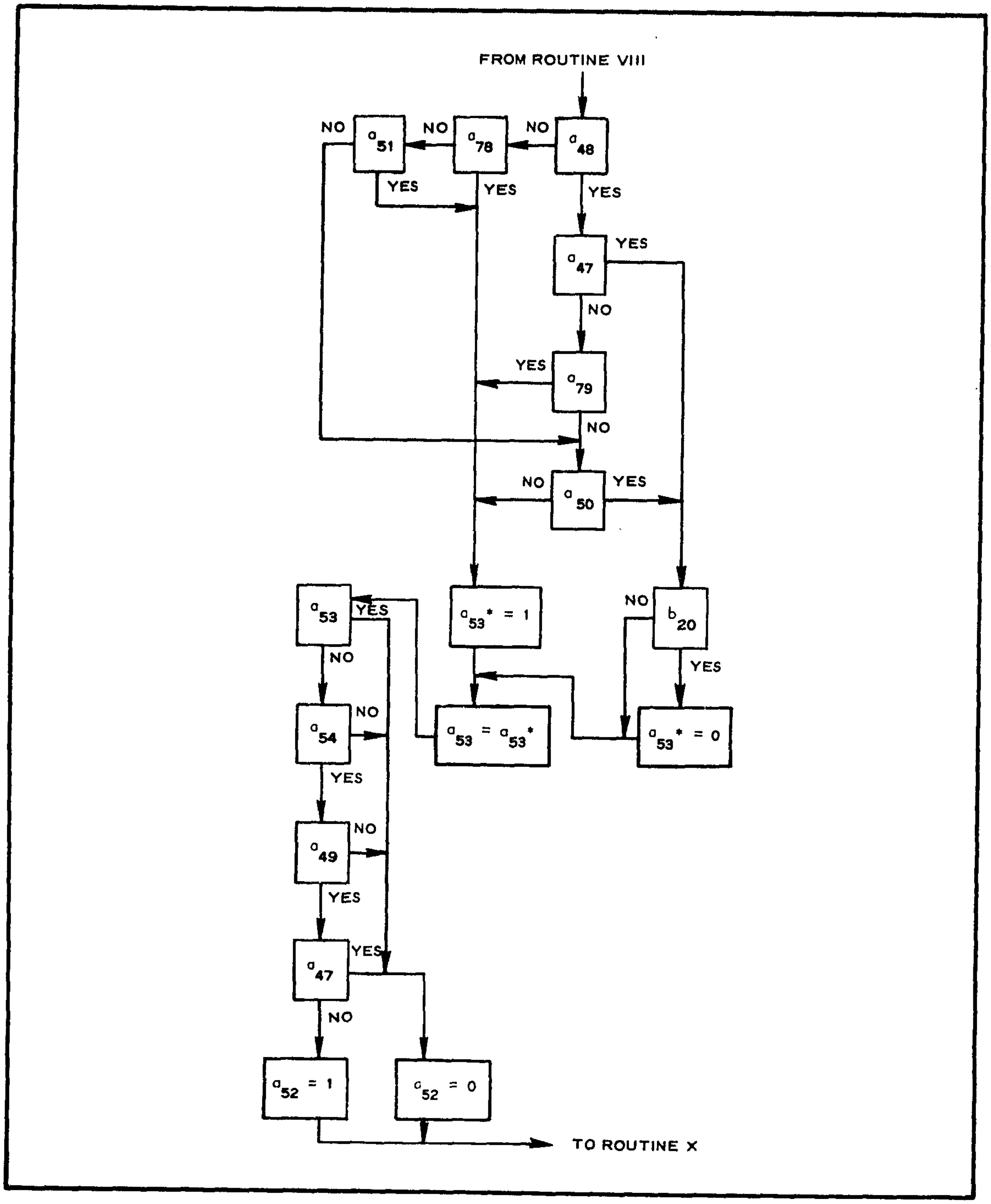

Figure D-24 - Compressor Stall and Flameout Routine I

a_{47}: - $\frac{W_f}{P_2} < \frac{W_{f_{max}}}{P_2}$.

a_{48}: - $\frac{W_f}{P_2} > \frac{W_{f_{min}}}{P_2}$.

a_{49} - Compressor stall requested by instructor.
a_{50} - Rich flameout requested by instructor.
a_{51} - Lean flameout requested by instructor.
a_{52} - Compressor stall to be simulated in engine simulation.
a_{53} - Engine flameout to be simulated in engine simulation.
a_{54} - $N > K_{15}$, where K_{15} corresponds to engine idle rpm.

a_{78}: - $\frac{W_f}{P_2} < K_{16} \frac{W_{f_{min}}}{P_2}$, where K_{16} designates the proportion of $W_{f_{min}}$ at which lean flameout is to occur automatically.

a_{79}: - $\frac{W_f}{P_2} > K_{17} \frac{W_{f_{max}}}{P_2}$, where K_{17} designates the proportion of $W_{f_{max}}$ at which rich flameout is to occur automatically.

b_{20} - Relight occurs, provided proper amount of fuel is supplied to the engine.

K. Afterburner Fuel Flow Routine.

The afterburner fuel control unit, like the main fuel control unit, can be considered to have a fuel-metering system and a computing system. Fuel obtained from the afterburner fuel pump, engine-driven like the main fuel pumps, is metered to afterburner spray bars in response to the thrust demanded by the throttle position selected by the pilot, but subject to minimum and maximum flow rates established by the computing system as a function of compressor discharge static pressure. The fuel limits essentially prevent inadvertent afterburner blowout from lean and rich fuel-air ratios. The maximum limit also prevents the maximum limitation on tailpipe temperature from being exceeded.

Normally, no fuel is permitted to flow to the afterburner until the throttle has been advanced from military to the minimum reheat detent on the throttle quadrant or beyond. However, during operation of the emergency afterburner modulation system, if one is provided, the afterburner demand switch is electrically bypassed and a flow of fuel to the afterburner is established even while the throttle is positioned in the idle-to-military range.

In either event, the actual rate at which fuel flows to the afterburner is determined by the fuel demand established in the fuel control unit and the amount of fuel available at the output of the afterburner fuel pump. During emergency modulation, the amount of fuel that would normally be supplied to the afterburner is supplemented by additional fuel to prevent lean afterburner blowouts from occurring at reduced engine speeds.

The computational flow diagram for the afterburner fuel flow routine, with provisions for introducing various malfunctions by the instructor, is shown in Figure D-25. The operations are defined below.

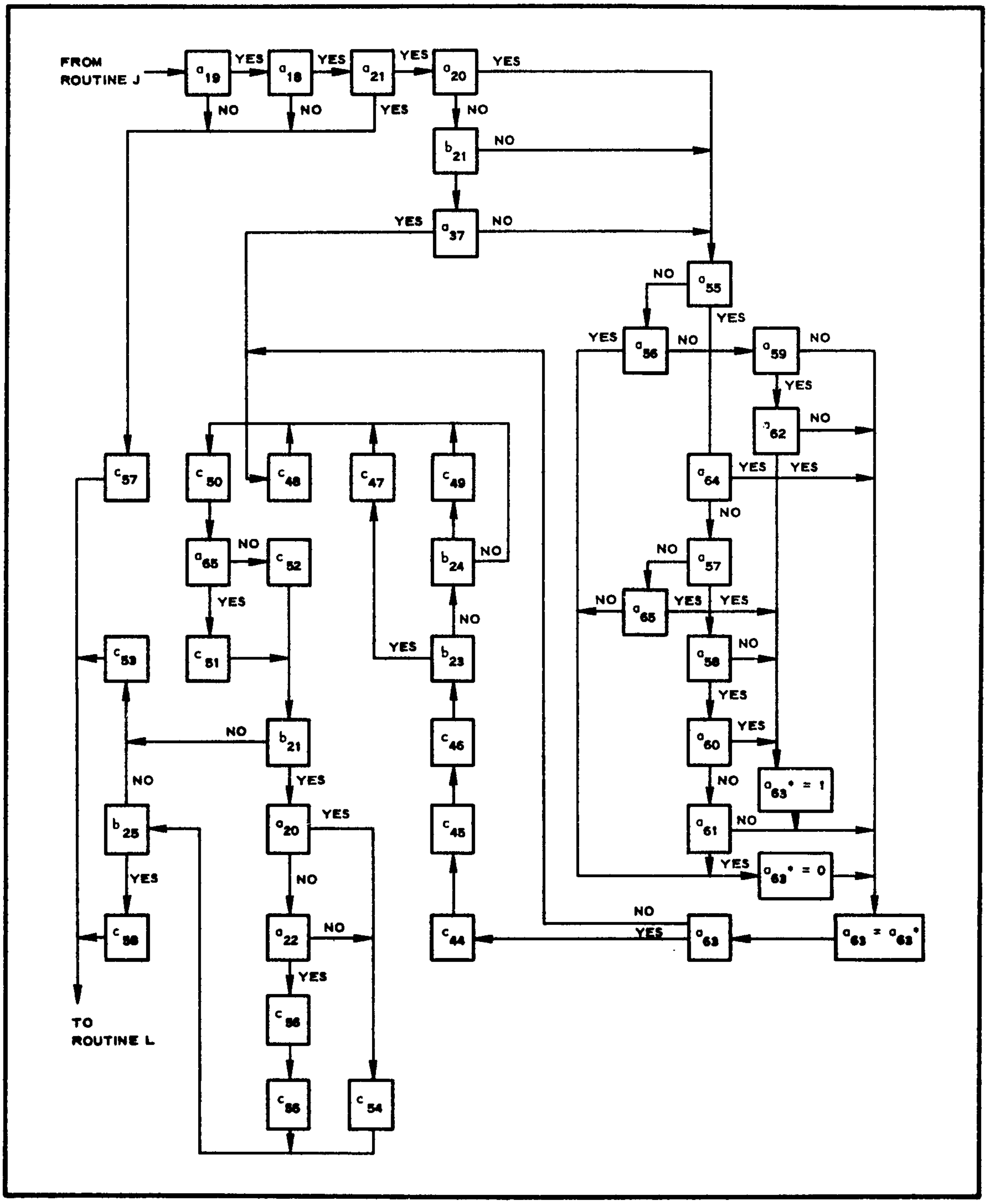

Figure D-25 - Afterburner Fuel Flow Routine

a_{18} - Fuel available at inlets to engine and afterburner fuel pumps.
a_{19} - Engine equipped with afterburner.
a_{20} - Afterburner fuel pump is separate from engine emergency fuel pump.
a_{21} - Failure of afterburner fuel pump by instructor.
a_{22} - Failure of engine fuel pump no. 1 (or engine stage) by instructor.
a_{37} - $\dfrac{W_{f_{avail}}}{P_2} \leq \dfrac{W_f^{**}}{P_2}$.
a_{55} - Electric power available for afterburner fuel control system operation.
a_{56} - Electric power failure closes afterburner shutoff valve.
a_{57} - $\alpha \geq K_{18}$, where K_{18} corresponds to throttle position at minimum reheat setting.
a_{58} - Afterburner equipped with speed lockout.
a_{59} - Afterburner equipped with emergency fuel shutoff valve mechanically opened and closed with throttle movement.
a_{60} - $N > K_{19}$, where K_{19} corresponds to the lowest engine speed at which the speed lockout allows afterburner operation to be initiated.
a_{61} - $N < K_{20}$, where K_{20} corresponds to engine speed at which afterburning is automatically terminated by the speed lockout; Note that $K_{19} > K_{20}$.
a_{62} - $\alpha > K_{21}$, where K_{21} corresponds to the throttle position where, assumming $a_{59} = 1$, the afterburner fuel shutoff valve goes from an open to closed position, or vice versa.
a_{63} - Afterburner fuel shutoff valve is open.
a_{64} - Afterburner fuel shutoff valve made inoperable by instructor.
a_{65} - Emergency afterburner modulation system is in operation.
b_{21} - $P_{eff} < 1$.
b_{23} - $W_{f_r} < W_{f_{rd}}$.
b_{24} - $W_{f_r}^{***} > W_{f_{rd}}$.
b_{25} - $W_{f_{ravail}} < W_{f_r}^{*}$.
c_{44} - $W_{f_{r_{min}}} = f_1 (P_{s_3})$.
c_{45} - $W_{f_{r_{max}}} = f_2 (P_{s_3})$.
c_{46} - $W_{f_{rd}} = (W_{f_{r_{max}}} - W_{f_{r_{min}}}) f_3 (\alpha) + W_{f_{r_{min}}}$.
c_{47} - $W_{f_r}^{**} = W_{f_r}^{***} + K_{22} \Delta t$, where K_{22} corresponds to fuel regulator gain constant.

c_{48} - $W_{f_r}^{**} = 0.$

c_{49} - $W_{f_r}^{**} = W_{f_r}^{***} - K_{22}\,\Delta t.$

c_{50} - $W_{f_r}^{***} = W_{f_r}^{**}$

c_{51} - $W_{f_r}^{*} = W_{f_r}^{**} + f_3\,(P_{s_3})$, where $f_3\,(P_{s_3})$ expresses the amount of supplemental fuel supplied during emergency afterburner modulation.

c_{52} - $W_{f_r}^{*} = W_{f_r}^{**}$

c_{53} - $W_{f_r} = W_{f_r}^{*}.$

c_{54} - $W_{f_{r_{avail}}} = f_3\,(P_{eff}).$

c_{55} - $W_{f_{r_{avail}}} = (W_{f_{r_{avail}}}/P_2)\,(P_2).$

c_{56} - $\dfrac{W_{f_{r_{avail}}}}{P_2} = \dfrac{W_{f_{r_{avail}}}}{P_2} - \dfrac{W_f}{P_2}.$

c_{57} - $W_{f_r} = 0.$

c_{58} - $W_{f_r} = W_{f_{r_{avail}}}.$

L. Afterburner Light-Off and Blowout Routine:

To initiate an afterburner light-off, the ignition system must be operable and a sufficient amount of fuel must be entering the afterburner. The minimum amount of fuel required for a light-off is essentially the same as the minimum limit discussed in the previous routine. In the digital simulation, an afterburner light-off occurs when the fuel flow to the afterburner has increased from zero to the minimum fuel schedule limit, assuming that a malfunction to prevent light-off has not been introduced by the instructor. Afterburner blowout corresponding to a lean fuel-air mixture occurs automatically when fuel flow drops below this minimum limit. In addition, a rich or lean afterburner blowout can be introduced by the instructor when fuel flow falls within certain limits imposed on the maximum and minimum limits, respectively. The computational flow diagram is shown in Figure D-26, and the operations are defined below.

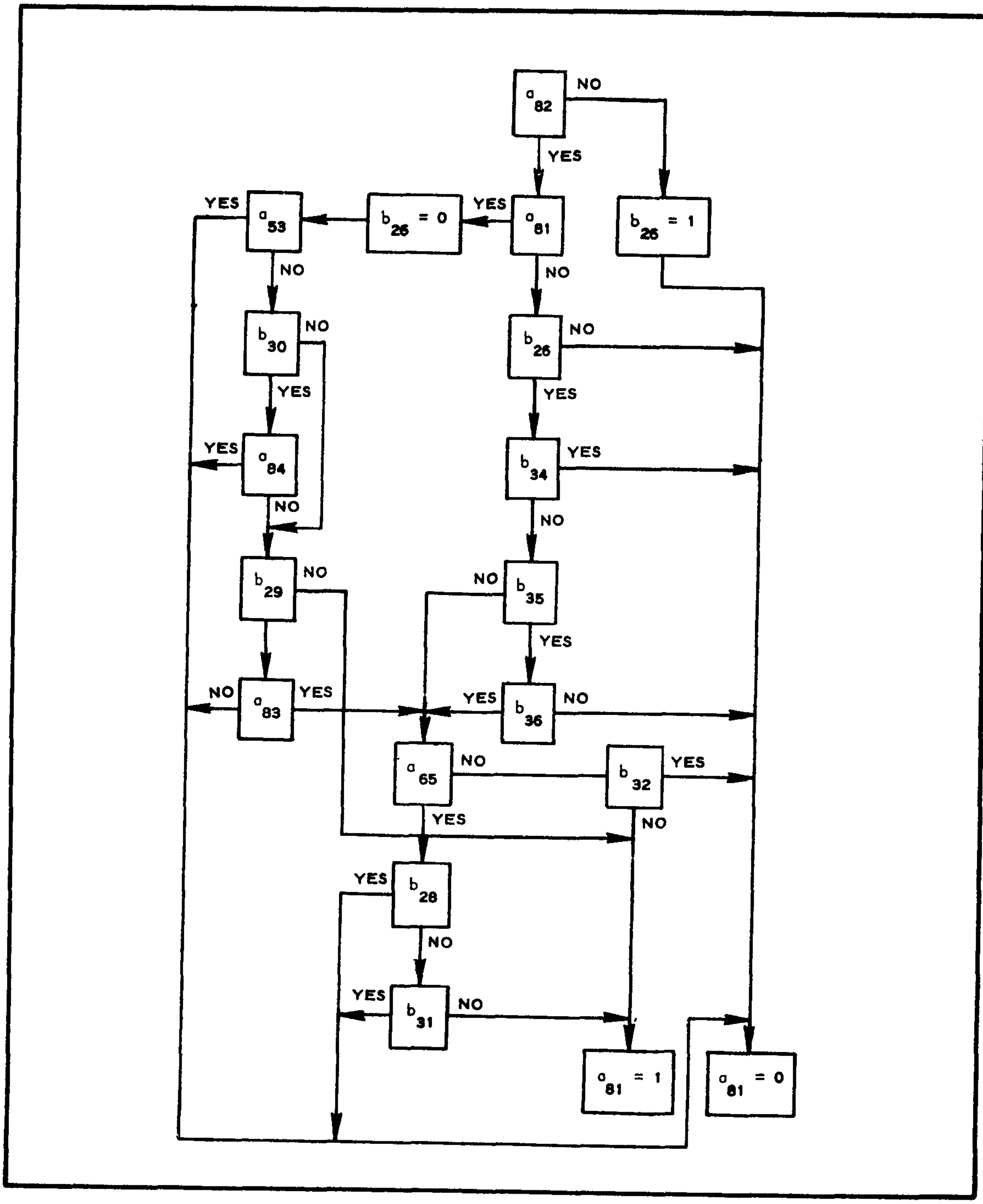

Figure D-26 - Afterburner Light-Off and Blowout Routine

a_{53} - Engine flameout.
a_{65} - Emergency afterburner modulation system in operation.
a_{81} - Afterburner light-off (in afterburning).
a_{82} - $W_{f_r} > 0$.
a_{83} - Lean afterburner blowout requested by instructor.
a_{84} - Rich afterburner blowout requested by instructor.
b_{26} - Afterburner recycled (refers to ignition system) and cleared of excess fuel.
b_{28} - $W_{f_r}^{***} < W_{f_{r_{min}}}$.
b_{29} - $W_{f_r} < K_{23} W_{f_{r_{max}}}$, where K_{23} is selected on basis of allowing the instructor to introduce a rich blowout under realistic rich blowout conditions ($K_{23} \approx 0.9$).
b_{30} - $W_{f_r} > K_{24} W_{f_{r_{min}}}$, where K_{24} is similar to K_{23} and applies to lean blowouts ($K_{23} \approx 1.1$).
b_{31} - $W_{f_r} < W_{f_r}^{*}$.
b_{32} - $W_{f_r} < W_{f_{r_{min}}}$.
b_{34} - Afterburner ignitor failed by instructor.
b_{35} - Electric power required for afterburner ignition system.
b_{36} - Electric power available for afterburner ignition system.

M. Jet Nozzle Area Routine.

Two types of exhaust nozzle controls prevail: two-position nozzles, where the exhaust area is increased only for afterburning; and continuously variable nozzles, where nozzle area is controlled by turbine exhaust gas temperature and throttle position for both dry and afterburner operation. In the former, the exhaust nozzle actuator control is activated by a pressure switch that senses the pressure in the afterburner fuel system. When the afterburner fuel shutoff valve is opened, the increase in the afterburner fuel system pressure causes the nozzle to open. When the shutoff valve is closed or when a sufficient loss in fuel pressure occurs, the nozzle automatically closes.

For the continuously variable nozzles, two modes of operation exits:

1. When the turbine exhaust-gas temperature is less than a fixed reference temperature, nozzle area is scheduled as a function of throttle position. However, a speed switch is sometimes incorporated to hold the nozzle fully open until engine speed increases above a preselected value to achieve faster rates of acceleration.

2. When the turbine exhaust temperature exceeds the fixed reference temperature, the nozzle is no longer controlled by throttle position but is automatically opened by a temperature override signal. The nozzle continues to open until the turbine exhaust-gas temperature stabilizes at the reference temperature. When the scheduled nozzle area becomes sufficient to prevent the reference temperature from being exceeded, the control system reverts to the throttle schedule. Normally, the temperature override control plays the dominant role during cruise, military, and afterburner modes of operation.

The effects of a nozzle control system malfunction on engine operation is a function of the nozzle area (that is, an open, closed, or intermediate position) in combination with the other engine parameter relationships established by the particular flight conditions existing at the time of a nozzle control system failure. When a nozzle control system fails, the resulting interaction between the nozzle and main fuel control systems can cause turbine overtemperatures, loss of engine thrust, speed overshoots, and unstable engine oscillations.

In the digital simulation, provisions are made for the instructor to introduce the various nozzle control system malfunctions that are associated with nozzle area scheduling, turbine temperature control, and nozzle actuator operation.

It should be noted that the turbine exhaust-gas temperature is measured by a thermocouple that produces a self-generated electrical signal. This signal actuates the exhaust temperature indicator in the cockpit, and it is also used as an input to the temperature amplifier of the nozzle control system. The dynamic response of the thermocouple varies with engine air flow, and can be represented by simple lag with a time constant of a few tenths of a second to several seconds in duration. This lag is compensated for in the nozzle control system but not in the temperature indicator reading. As a result, for low engine air flows, such as during engine starting, the effect of this lag can be detected by the pilot. Provisions for generating a temperature indicator signal with the effects of the thermocouple lag is therefore included in the digital simulation.

The functional diagram of the nozzle area routine is shown in Figure D-27; the operations are defined below.

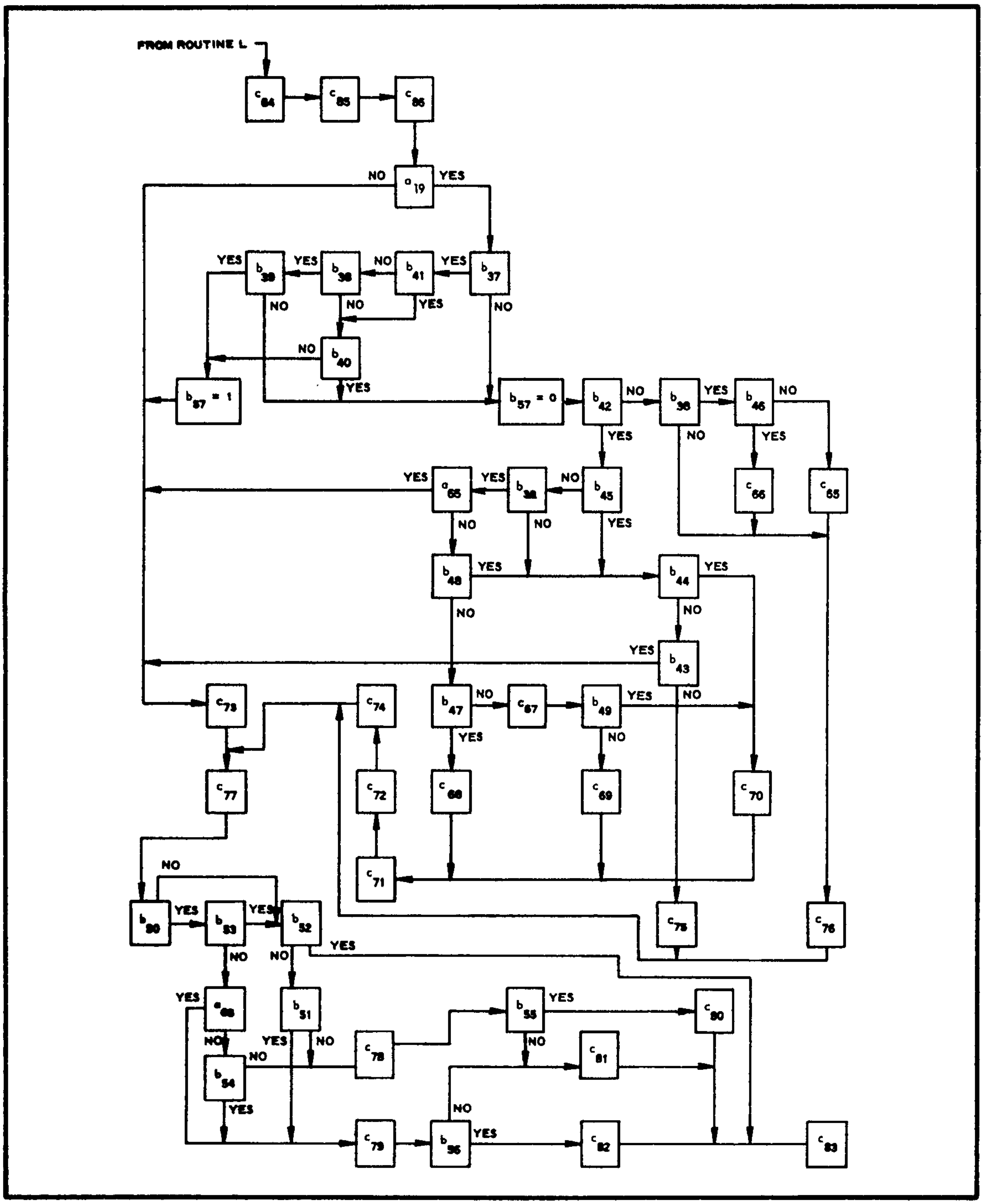

Figure D-27 - Jet Nozzle Area Routine

a_{19} - Engine equipped with afterburner.
a_{65} - Emergency afterburner modulation system in operation.
b_{37} - Engine equipped with speed switch for enabling faster engine accelerations.
b_{38} - Electric power available for nozzle control system operation..
b_{39} - $N < K_{25}$, where K_{25} equals speed at which speed switch "cuts" in or out.
b_{40} - Electric power failure deactivates acceleration speed switch (slower accelerations).
b_{41} - Acceleration speed switch failed by instructor.
b_{42} - Nozzle equipped with temperature override.
b_{43} - Electric power failure will cause a temperature override signal that calls for a fully open nozzle (program $\bar{b}_{43}$ if nozzle goes fully closed).
b_{44} - Electric power failure reduces the temperature override control signal to zero, so that it has no effect on further changes in nozzle area.
b_{45} - Temperature override control failed by instructor.
b_{46} - $W_{f_r} > 0$.
b_{47} - $T_5 > T_{5_{reference}}$.
b_{48} - Thermocouple failed by instructor.
b_{49} - $(A8)_{T_5}^{**} > 0$.
b_{50} - Power available for operating nozzle actuators.
b_{51} - Actuator power failure causes nozzle to go fully open (use $\bar{b}_{51}$ if nozzle goes fully closed).
b_{52} - Actuator power failure stops nozzle movement.
b_{53} - Nozzle actuator(s) failed by instructor.
b_{54} - $A8_D > A8^*$.
b_{55} - $A8^{**} < A8_{min}$.
b_{56} - $A8^* > A8_{max}$.
b_{57} - Speed switch activated.
c_{65} - $A8^{**} = A8_{max}$.
c_{67} - $A8_{T_5}^{**} = A8_{T_5} - K26\ \Delta t$, where K26 corresponds to loop gain of temperature override control.
c_{68} - $A8_{T_5}^{**} = A8_{T_5} + K26\ \Delta t$.
c_{69} - $A8_{T_5}^{*} = A8_{T_5}^{**}$.
c_{70} - $A8_{T_5}^{*} = 0$.
c_{71} - $A8_{T_5} = A8_{T_5}^{*}$.
c_{72} - $A8\ \alpha = F_3\ (\alpha)$.
c_{73} - $A8_D^{*} = A8_{max}$.
c_{74} - $A8_D = A8_{T_5} + A8\ \alpha$.

c_{75} - $A^{*}_{8D} = A_{8min}$.
c_{76} - $A^{*}_{8D} = A^{**}_{8}$.
c_{77} - $A_{8D} = A^{*}_{8D}$.
c_{78} - $A^{**}_{8} = A^{*}_{8} - K_{27}\,\Delta t$, where K_{27} corresponds to loop gain of jet nozzle serving system.
c_{79} - $A^{**}_{8} = A^{*}_{8} + K_{27}\,\Delta t$.
c_{80} - $A^{*}_{8} = A_{8min}$.
c_{81} - $A^{*}_{8} = A^{**}_{8}$.
c_{82} - $A^{*}_{8} = A_{8max}$.
c_{83} - $A_{8} = A^{*}_{8}$.
c_{84} - $\Delta T_{5indicator} = \frac{1}{K_{28}}(T_5 - T_{5indicator})$, where K_{28} corresponds to thermocouple time constant appropriate for low engine air flows.
c_{85} - $T^{*}_{5} = T_{5indicator} + \Delta T_{5indicator}$.
c_{86} - $T_{5indicator} = T_5$.

N. Inlet Guide Vane and Acceleration Air Bleed Routine.

The inlet guide vanes and the variable compressor stator baldes, if provided, are positioned as a function of rotor speed and compressor inlet temperature by a common control system. The usual procedure followed in simulating the thermodynamics of a jet engine equipped with variable stators is to assume that the stators remain on schedule. In the more complex engine simulations, the effects of off-schedule stators are included, but at the expense of using a separate compressor map for each off-schedule stator position so selected. It is doubtful if this amount of complexity is warranted for trainer simulator purposes. Assumming that it is not, the digital routine employed herein is based on stators that are on schedule, except during one condition as a consequence of including the effects of afterburner emergency modulation in the simulation; that is, the inlet guide vanes and stator blades are energized closed when the emergency afterburner modulation system is activated. In conjunction with this exception, provisions are also made for the instructor to fail the inlet guide vanes and stator blades in a closed position.

On some aircraft engines, air is bled from the compressor to obtain faster rates of rotor acceleration. The air bleed valves are opened and closed in conjunction with the operation of the

speed switch discussed in Routine L and the operation of the emergency afterburner modulation system discussed in Routine G .

The computational flow diagram in Figure D-28 shown below establishes:

1. Whether the inlet guide vanes and stator blades are on schedule or closed
2. Whether compressor acceleration air bleed valves are opened or closed

The operations are defined below.

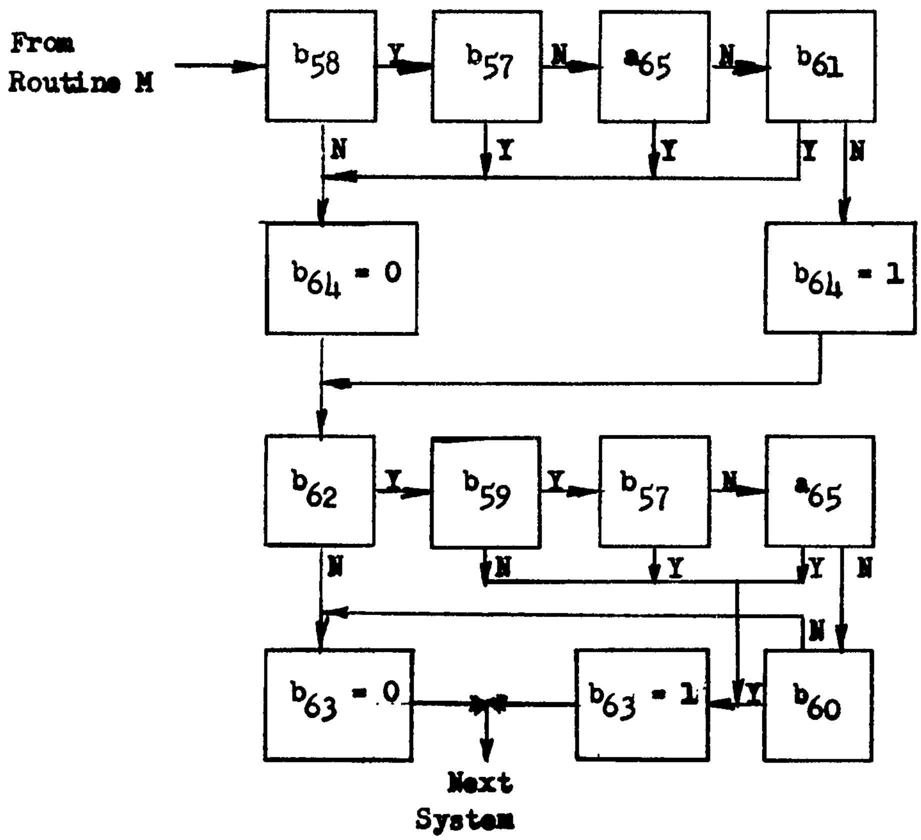

Figure D-28 - Subroutine XIV for Inlet Guide Vanes and Air Bleed

b_{57} - Speed switch activated.
a_{65} - Emergency afterburner modulation system is in operation.
b_{58} - Actuator power available to inlet guide vane and stator blade control system.
b_{59} - Electric power available to operate compressor acceleration air bleed valves.
b_{60} - Acceleration air-bleed valve solenoid failed by instructor.
b_{61} - Inlet guide vane and stator blade control system failed by instructor.
b_{62} - Acceleration air-bleed valves provided on engine.
b_{63} - Compressor acceleration air-bleed valves open.
b_{64} - Inlet guide vanes and stator blades positioned on schedule; b_{64} yields fully closed position.

SECTION X. APPENDIX E - AIRCRAFT FUEL SYSTEM SIMULATION

A. Introduction.

One of the most important aspects of simulating a manned aircraft is that the simulation must convery a realistic control "feel." When the airplane is flying in a "clean" configuration, its response to control movements is considerably faster than when it is flying in a configuration such as "clean" plus two wing tanks and, say, a missile at the central store station. One of the major factors that contributes to the changing control "feel" is the rate of fuel consumption. As the engines consume fuel, the cg of the airplane can shift, the trim requirements change, and the turning moments about all three axes change.

There are essentially two prime requirements of a fuel system simulation. The first is to reproduce fuel system changes realistically, as they occur in response to the pilot's decisions, and to report them to the aerodynamics section of the simulator computer so that the appropriate flight factors can be adjusted.

The second requirement of a fuel system simulation is that it furnish proper cockpit indications for training the student in both normal and emergency procedures.

In most aircraft considered in this study, the fuel system components are divided into (1) the aircraft fuel system and (2) the engine and afterburner fuel system.

The aircraft fuel system is concerned with the storage of fuel [illegible] transfer to the engine fuel system. The engine fuel [illegible]ceives the fuel from the aircraft fuel system and [illegible]es the proper rate of delivery to the engine. In some [illegible], the afterburner system is a separate entity; in others, [illegible] the engine system are employed in the afterburner system. [illegible] fuel system is considered separately in the engine [illegible] simulation. The aircraft fuel system simulation deter[illegible] amounts of fuel in each storage location as outputs [illegible] aerodynamics section of the computer. The aerodynamics [illegible] of the computer then determines the turning moments of [illegible]craft. In addition, the aircraft fuel simulation determines the conditions under which fuel can be supplied to [illegible](s), considering rates of delivery, pressures, pilot [illegible], and instructor inputs. In the course of these com[illegible] the fuel system status will be properly read out [illegible]it indicators and the instructor's indicators.

It is desirable to use an "assembler" program to particularize the general case to the specific aircraft being simulated. The assembler portion of the simulation will be presented so that it can be done by hand by the programmer. The assembly program could, of course, be programmed for the digital computer and would be much more efficient if handled in this manner.

B. Assembly Program.

The aircraft fuel system is composed of the various components summarized in Table E-I.

Table E-I - Fuel System Components

Item	Description
Tanks	Engine service Fuel storage Negative g Droppable Self-sealing Pressurized May have leaks
Valves	Float type Solenoid automatic Solenoid pilot controlled Check valve Manual
Pumps	Manual (emergency) Electrical (ac) Electrical (dc) Hydraulic Gravity Ram air May be in parallel May be in series May be inoperative

Table E-I - Fuel System Components (Continued)

Item	Description
Indicators	Indicate fuel quantities in certain tanks or combinations of tanks Indicate flow rates Indicate low level warning Indicate fuel pressure Indicate flow-no flow
Auxiliary equipment	Heaters Purge gas generator Auxiliary equipment
Miscellaneous components	Strainers Vents Refueling probes

The first task to be performed in computing the fuel system is to determine the precise state of the system for this iteration. This will be accomplished by reading instructor-student switching decisions into the computer by some type of analog-to-digital device and using this information to open or close fuel transfer paths. The objective at this point is to determine the status of a fuel transfer schematic similar to the one shown in Figure E-1. The conducting status of the flow paths as shown is primarily dependent on the status of the valve(s). However, if the line utilizes a pump, and the pump is inoperative, fuel may not be transferred even if the valve is open. Each tank must have an input and an output manifold. The input switching logic must set each manifold control word to reflect the conducting status (conducting or not conducting) of each line contributing flow to the manifold. In cases where multiple valves are in a flow path, the initial logic must determine if the combination of conditions opens or closes the path, and then use this information to set the manifold control word.

The manifold control word will have one digit for each flow path. This digit will indicate "conducting" or "not conducting". In the case of a pump failure by the instructor, the logic will check the operating status of all pumps in the flow paths of the

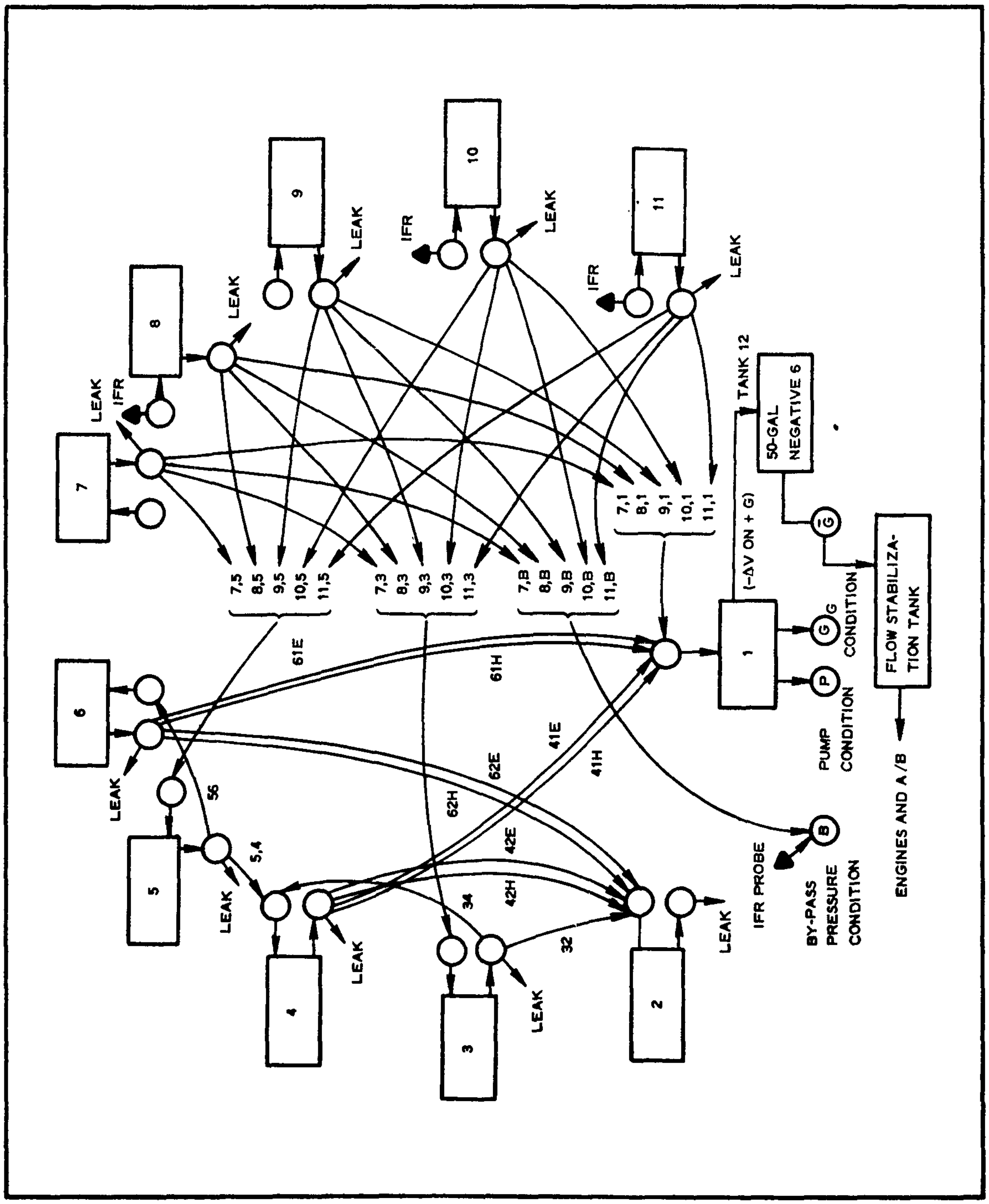

Figure E-1 - Fuel Transfer Schematic (F4H)

manifold and if one pump is inoperative, it will set a one-digit "flag" in the manifold control word to off. The purpose of this "flag" is to provide a means to stop the automatic recycling feature of the logic and determine the new conditions of operation. In this assembler program section, the programmer must determine exactly which valves are in each flow path. He must then relate the input information to these valves. The following paragraphs will describe the method of setting up the fuel transfer graph and its associated flow paths.

The components of a typical fuel system are shown in Figure E-2. To facilitate the construction of the assembler program, the fuel system shown will be transformed into a "transfer schematic" of the fuel system shown in Figure E-1. It is recommended that for each fuel system to be simulated, a similar schematic be constructed. The rules of constructing the schematic can be summarized as follows:

1. Determine the correct number of fuel "sinks" or fuel consuming devices (engine(s), afterburner(s), auxilliary equipment) that will demand fuel from the system.
2. Engine service tanks should be centrally located, since all the storage tanks must feed into them.
3. Each tank is represented with all input lines entering a single input manifold.
4. For each tank, all output lines exit from a common output manifold.
5. Interconnecting lines are directional and represent possible paths of fuel flow, even though a path may require two or more valves to open for flow to commence, or two or more paths may share a common pipeline.
6. All possible paths must be included. (It is the responsibility of the programmer not to include trivial cases, however.) In Figure E-2, the notation on the interconnecting lines indicates first the number of the supply tank, and next the number of the receiving tank. (It is convenient to represent the negative-g feature as a separate tank of limited capacity from which fuel is used when the aircraft is in the negative-g attitude.) In cases where the two tanks are connected by multiple lines, it is necessary to specify lines

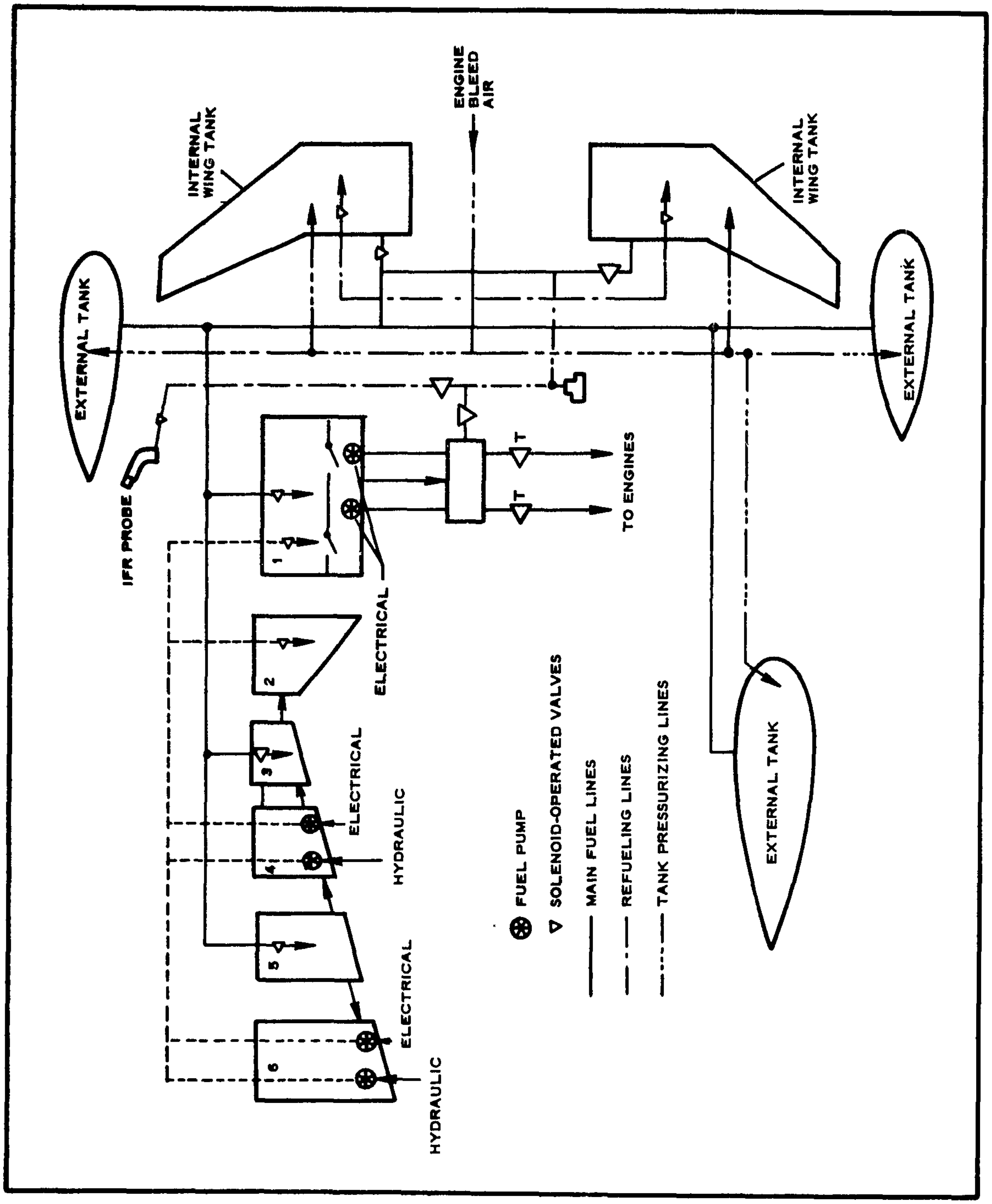

Figure E-2 - F4H Fuel System

as H(hydraulic), E(electric), P(pressure), or G(gravity). Pressure gravity lines are computed as one line.

Once the transfer schematic is completed, the pattern of the assembly program can be clearly visualized. It is quite difficult and very inefficient, from a computer standpoint, to develop a program that is general enough to include all aspects of all aircraft fuel systems. This is where the machinery of a computer assembler program would be so desirable. With such a program, the computer could do the manual labor of setting up flow paths, determining flow logic, etc., and the data inputs would merely be a precise statement of the aircraft system. However, the assembler program can be accomplished by hand with a straightforward, though tedious, technique. After the transfer schematic is complete, it must be converted into machine logic. The first step in accomplishing this is to organize the initializing logic. The following procedure is recommended as a guide to the programmer in the determination of the initial flow logic.

There are three types of logic inputs that determine the state of the system for any one computation cycle, as follows:

1. Pilot switching inputs such as:

    a. Fuel transfer
    b. Tank selector
    c. Fuel dump
    d. Engine prime
    e. Cross-feed
    f. Bypass
    g. Emergency jettison
    h. Purge valve
    i. Emergency fuel pump
    j. Drop tanks
    k. Refueling

2. Instructor inputs such as:

    a. Leaks
    b. Transfer pump failure
    c. Booster pump failure
    d. Emergency fuel pump failure

3. System inputs such as:

   a. Electrical power not available
   b. Ram air insufficient
   c. Compressor bleed air not available
   d. Hydraulic power not available
   e. "G" not within limits

System inputs will be automatically picked up by the program. For example, if the hydraulic system has failed, the program will find no such power available to drive the hydraulic fuel pumps. The pilot and instructor fuel switching options should be listed in a table, similar to Table E-II. The information for the table can usually be obtained from the pilot's operating manual for the aircraft; Table E-II was based on the F4H pilot's handbook.

Table E-II - Fuel Switching Options

Switch	Conditions	Requirements
Fuel tank selector		28-v d-c left main essential, switch power
Auto	No fuel transfer until fuselage fuel $\leq$ 5700 lb. When fuselage fuel $\leq$ 5700 lb, transfer will begin to fuel cell 3.	
Man Override	If EXT. TRANS switch is OFF, fuel transfer is enabled when fuselage fuel $<$ 5700 lb. If EXT. TRANS switch is not in OFF position and if remaining fuel $<$5700 lb, this position enables transfer to cells 5 and 6.	

Table E-II - Fuel Switching Options (Continued)

Switch	Conditions	Requirements
STOP TRANS	Stops fuel transfer to fuselage tanks; closes internal wing and external wing transfer valves.	
WING TRANS. Switch		Switch power 28-v d-c essential
Normal	If landing gear handle is up, this position enables pressurization of all internal and external tanks; it opens pressure regulator valves and closes pressure relief valves.	
Emergency	Allows tank pressurization with gear down, if air pressure is available.	
EXT. TRANS Switch		Either
Center	Opens center tank transfer valve; closes internal wing transfer valve, if left main 28-v d-c power is available to power INT. and EXT. transfer valves.	Right wing 28 v dc and wing TRANS switch in EMERGENCY. or right main 28 v d-c and air pressure available and landing gear handle in the up position

Table E-II - Fuel Switching Options (Continued)

Switch	Conditions	Requirements
Outbound	Opens left and right external wing transfer valve, closes internal wing transfer valve. If left main 28 v d-c power is available.	
OFF	Closes center, left and right wing transfer valve opens internal wing transfer valve.	
EXT. TANK JETTISON	(Switch can be operated at any time). If EXT. TRANS switch is in outboard position, extension shutoff valves close, and switch is disabled. Wing transfer is enabled to transfer normally.	28-v d-c bus
EXT. STORES EMER. RELEASE BUTTON	Jettisons only center store, whether empty or full. If EXT. TRANS switch is in CENTER position, switch will close centerline fuel shutoff valve and will enable wing fuel to transfer normally.	28-v d-c essential bus

Table E-II - Fuel Switching Options (Continued)

Switch	Conditions	Requirements
Bomb Control (DIRECT Position) plus BOMB RELEASE BUTTON	Releases center store; center tank TRANS valve closes, wing fuel transfer enabled.	28-v d-c bus
WING FUEL DUMP		
Normal	No effect	
Dump	Opens left and right wing dump shutoff valves; closes wing transfer and vent valves. Wing tank pressure regulator opens to maintain tank pressurization and air supply remains on until switch is placed in NORMAL).	
ENGINE MASTER Switch		
ON	Enables fuel booster pumps to operate if power is available. Enables fuel transfer pumps to operate if power is available. Completes circuit for fuel shutoff valves, if power is available. EXTERNAL HYDRAULIC power supply will operate the hydraulic fuel pumps in tanks 4 and 6.	

Table E-II - Fuel Switching Options (Continued)

Switch	Conditions	Requirements
	Right engine boost pump will operate if left main a-c power is available. Left engine boost pump will operate on high speed if right main a-c power and 28-v d-c relay power is available. Operates at low speed for NO aircraft a-c electric power, if wind-driven turbine is lowered and 28-v d-c essential power is available.	

With the aid of the fuel system drawing and the transfer schematic, a table can be constructed for the initial switching logic. This can be done by considering all lines associated with each manifold of the transfer schematic. In this table, each flow path of the transfer schematic, its associated valve combination, and the pump operational status for the line should be considered. This statement of line conditions is next transformed into the initial switching logic for the fuel system program. The table of fuel-switch functions is very useful in performing this operation. It must be remembered that valve power requirements must be checked, and interlocking circuits must be included in the logic. An example will illustrate the procedure.

The input manifold of the engine service tank (tank 1) of the fuel transfer schematic shown in Figure E-1 will serve as an example to illustrate the procedure. Table E-III lists the

line elements for the manifold, and Figure E-3 shows the resulting logic when the Table is converted into flow chart form.

Table E-III

Input lines	Valve Combinations Required	Pump Combination
2,1	G	Air P
4,1,E	-	Electrical
4,1,H	-	Hydraulic
6,1,E	-	Electrical
6,1,H	-	Hydraulic
7,1	V_1, V_2	Air P
8,1	V_3, V_2	Air P
9,1	V_2	Air P
10,1	V_4, V_2	Air P
11,1	V_5, V_2	Air P

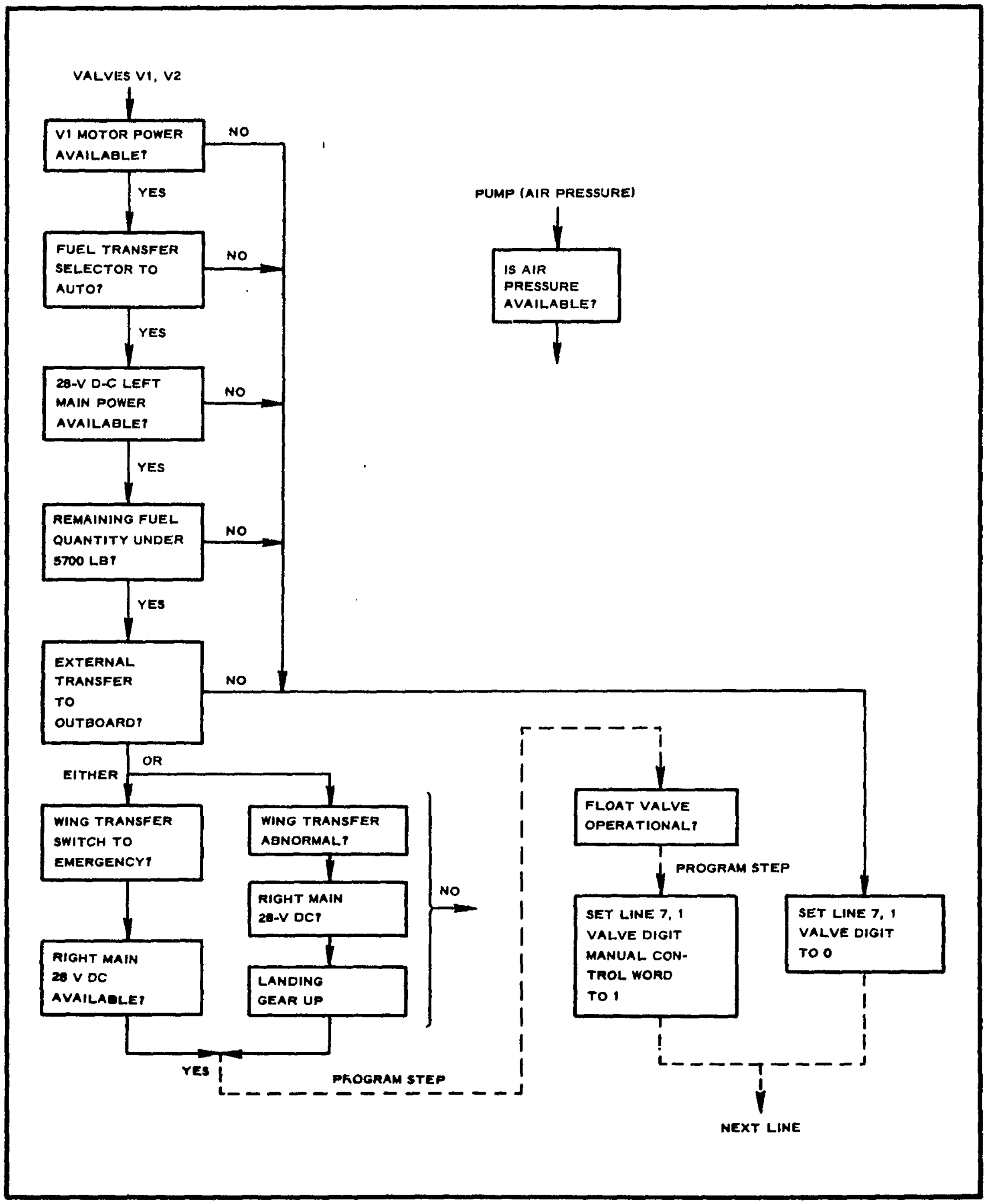

Figure E-3 - Necessary Logic to Determine Path 7,1 Conducting Status

The numbers are for F4H are as follows:

1 through 6	-	See Figure E-1
7	-	Left Wing external
8	-	Right Wing external
9	-	Center external
10	-	Left wing internal
11	-	Right wing internal

The valves are of the following types:

V_1 = MOSOV, motor-operated shutoff valve
V_2 = RLCV, refueling level control
V_3 = MOSOV, see Figure E-1
V_4 = SOT and LLSOV, solenoid operated transfer and low-level shutoff valve
V_5 = See Figure E-1

The initial logic should be completed, as shown in the example, for all lines of all manifolds. After the initial logic has determined the state of the system for this iteration, the actual computation of fuel transfer can be undertaken.

It is necessary at this point to define the transfer functions for the flow paths of the transfer schematic. If fuel is to flow from one point of the system to another, there must be a sufficient difference in hydraulic head between the points to overcome transmission resistance. This difference in head can be provided by one or more of the following conditions:

1. A pressure difference between the supply and receiving tank
2. A difference in elevation between the tanks (gravity feed)
3. A pump supplying transfer energy, such as:
   a. Hydraulic pump
   b. Electric pump
   c. Pneumatic pump
   d. Other types for which the output conditions are known

1. Cases 1 and 2.

For cases 1 and 2 it can be shown that the flow characteristics are described by the following equation from Reference 1:

$$R = \sqrt{\left(\frac{\Delta P}{w} - \Delta h\right) 2\ g} \cdot \left[\left(60\ \frac{sec}{min}\right) A_{pipe}\right] ,$$

where

- R is in $\frac{ft^3}{min}$,
- ΔP = pressure differential between the two points in feet of hydraulic head,
- w = specific weight of fuel (for kerosine, w = 0.84),
- ΔH = difference in elevation between the two points,
- g = force of gravity, and
- A = cross-sectional area of pipe.

This equation will produce a parabolic pressure-rate curve similar to that shown in Example C of Figure E-4. Using the above equation, the programmer can quite simply construct such a parabolic curve for any given pressure-gravity fuel transfer situation. One can make a reasonably good approximation to a parabolic curve by selecting two linear segments over the range of possible values, that most nearly coincide with the curve. It is convenient to represent these line segments in the following notation:

1. $(P_{max}, R_o = 0)$
2. m_1 = slope of line segment 1 joining (P_{max}, R_o)
3. (P_1, R_1)
4. m_2 = slope of line segment joining (P_1, R_1) to $(P_o = 0, R_{max})$
5. $(P_o = 0, R_{max})$

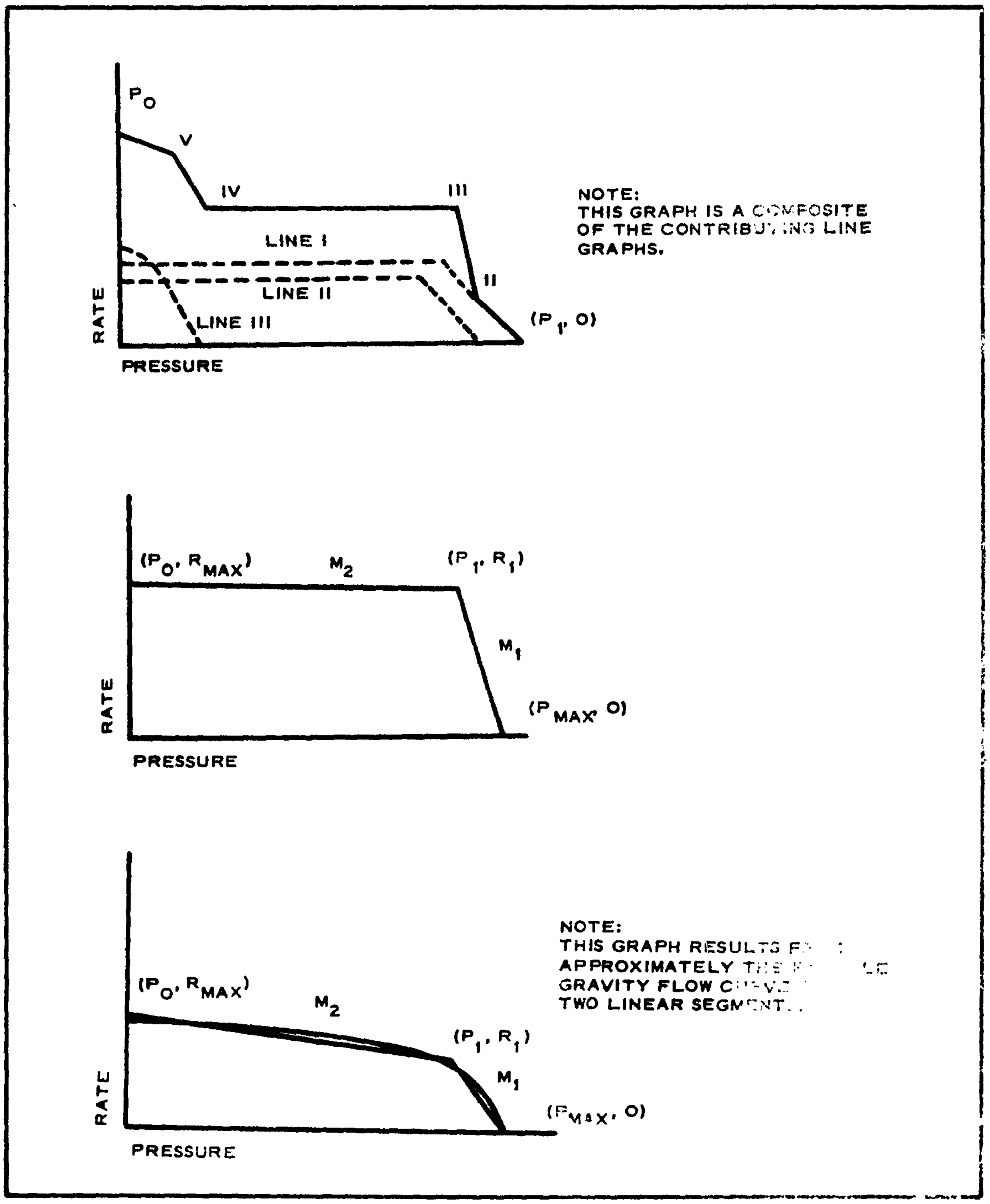

Figure E-4 Fuel Flow Rate vs Pressure for Various Conditions

The possible values for a pressure-gravity transfer must include all admissible ranges of pressure plus "head" difference due to elevation. Once the midpoint (P_1, R_1) is selected, the linear segments can be defined in the plane by computing slopes m_1 and m_2 of the segments between the end points. The computational logic will adjust P_{max} for the curve to fit the conditions at time n_1 by reading the total difference in pressure head plus the elevation difference between tanks. It is apparent that the entire set of transfer conditions for a given line can be stated by six words in memory: P_{max} (R_o is understood to be zero), m_1, P_1, R_1, m_2, and R_{max} ($P_o = 0$).

2. Case 3.

For case 3, fuel transfer pumps are described by the manufacturer by a pressure-rate curve similar to Example B in Figure E-4. The information for the curve can be obtained from the aircraft maintenance manual or from the aircraft manufacturer. The curve can obviously be described by the same format as the pressure-gravity case above; namely, P_{max}, m_1, P_1, R_1, m_2, and R_{max}. It should be obvious to the programmer that he can make excellent use of the symmetry involved in the statements of the transfer functions.

The main advantage of this seemingly cumbersome approach is that it is relatively easy to adjust the transfer functions for the dynamic situation of the aircraft. To do this, the program logic takes all conducting lines for a given manifold and alters their transfer functions with incremental differences in tank pressure and lift at the particular time n, similar to Example A in Figure E-4. Then, as the total demand pressure or rate is specified for the manifold, contributing rates and pressures of all lines can be found. The attitude of the aircraft and the variations in tank pressures can appreciably change the dynamic situation for the manifold. By using the foregoing solution technique, one can avoid the formidable difficulties encountered by manipulating multiple line transfer equations. In addition, all lines can be stated in an identical format whose symmetry should appeal to the programmer. It should also be apparent that this method has much inherent generality and with the investment of some ingenuity, the programmer can simulate nearly any fuel transfer situation.

Using the techniques outlined above, the programmer can form the transfer functions for all lines on all manifolds. These data should then be arranged for storage in the computer memory. Input manifolds only are required since, once all the rates are determined for all the input lines, the output lines are also known. In practice, the control word feature will prove very valuable time-wise, since there will be periods of flight when large portions of the fuel simulation can be by-passed because valves will be closed or tanks empty. The computational logic requires, in addition to the line transfer functions, the following information for each tank:

1. Manifold control word
   a. Attitude bit
   b. Each line conducting, or not
   c. Leak open or closed
   d. Vent open or closed
   e. Pumps operational, status bit

2. Line conducting conditions

a.	Fuel is available in supply tank	Yes	No
b.	Receiving manifold can accept fuel	Yes	No
c.	Valve(s) operating, power available	Yes	No
d.	Valve is operational	Yes	No
e.	Pump(s) power available	Yes	No
f.	Pump(s) operational	Yes	No

3. Tank characteristics

a.	Self-sealing	Yes	No
b.	Pressurized	Yes	No
c.	Maximum volume	V_{max}	
d.	Present volume	V_n	
e.	Number of input lines	L_{in}	
f.	Number of output lines	L_{out}	
g.	Droppable	Yes	No
h.	Iteration count	T_n	

4. Manifold control word for last iteration
5. Line rates for last iteration

With this information, the initial logic section of the assembler program is completed. The next section of the program computes the volumes in each tank and the volumes consumed by all using devices. When this step is accomplished, the fuel system is

completely determined and the information is ready to be read out to the cockpit indicators, instructor's indicators, and to other sections of the computer that require the information. For this latter operation, the programmer must list the quantities to be read out and arrange for the necessary digital-to-analog facilities.

C. Subroutine I.

Subroutine I shown in Figure E-5 gives the sequence of operations necessary to determine the manifold control words for this iteration. The input data for this subroutine are given in the assembler program. The purpose of the manifold control word is to choose only the active lines for later computation. This system will materially cut the average computation time and simplify the remaining computations. Primarily the manifold control word answers the questions:

1. Is this line enabled to conduct, considering the valve(s) status?
2. Is there a pump in the combination of manifold lines that is inoperative?

The operations for Subroutine I are defined below.

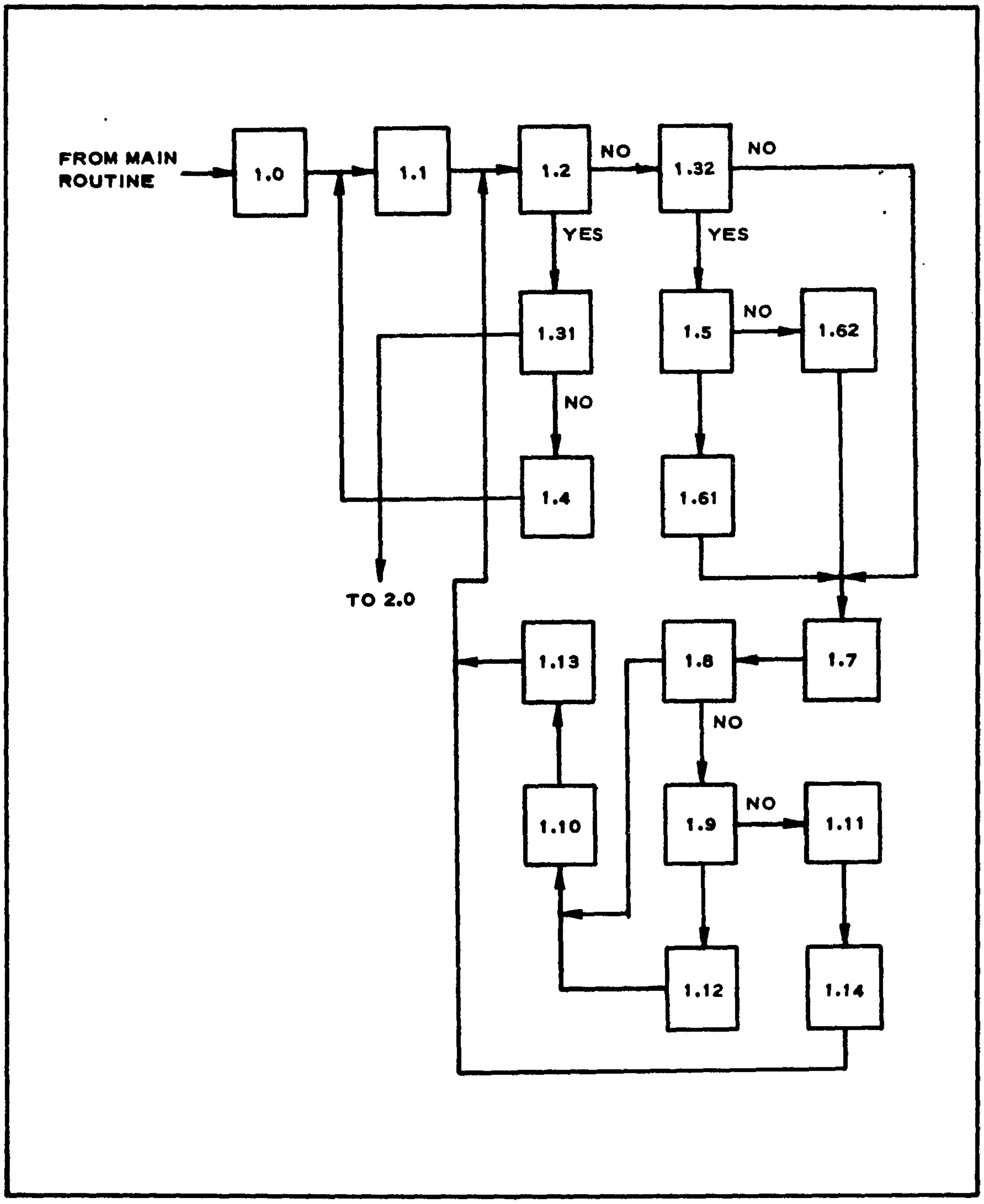

Figure E-5 - Subroutine I - Operational Sequence of Initial Logic

1.0 - Read and store analog-to-digital switching inputs.
1.1 - For manifold M, set line counter to the number of active lines.
1.2 - Does line counter read ≤ 0?
1.31 - Is this the last manifold to be computed?
1.32 - Does this line have a pump?
1.4 - Determine next manifold to be computed.
1.5 - Is pump operative? (input data).
1.61 - Set pump digit of manifold control word (M.C.W.) to 1.
1.62 - Set pump digit of manifold control word to 0.
1.7 - For this line there are k_v valves; set valve counter to k_v.
1.8 - Does valve counter read ≤ 0?
1.9 - Is valve k_v open or closed? (input data).
1.10 - Set this line's valve status digit to 1.
1.11 - Add -1 to valve count.
1.12 - Set line valve status digit to 0.
1.13 - Add -1 to line count.
and 1.14

D. Subroutine II.

There are, in addition to the valve and pump logic, several special considerations that must be examined before the status of the system is completely determined. Subroutine II, shown in Figure E-6, is designed to determine this condition so that the following computation can be done in an efficient manner. The considerations covered in this subroutine are:

1. Negative g supply
2. Attitude limits for recycling
3. Jettison operation
4. Refueling operation

These are basic considerations to most aircraft covered in this study. For a specific aircraft, there may be additional special cases that should be covered in this portion of the program. The programmer should consider this subroutine as an outline that can be expanded if he deems necessary. The operations for Subroutine II are defined below.

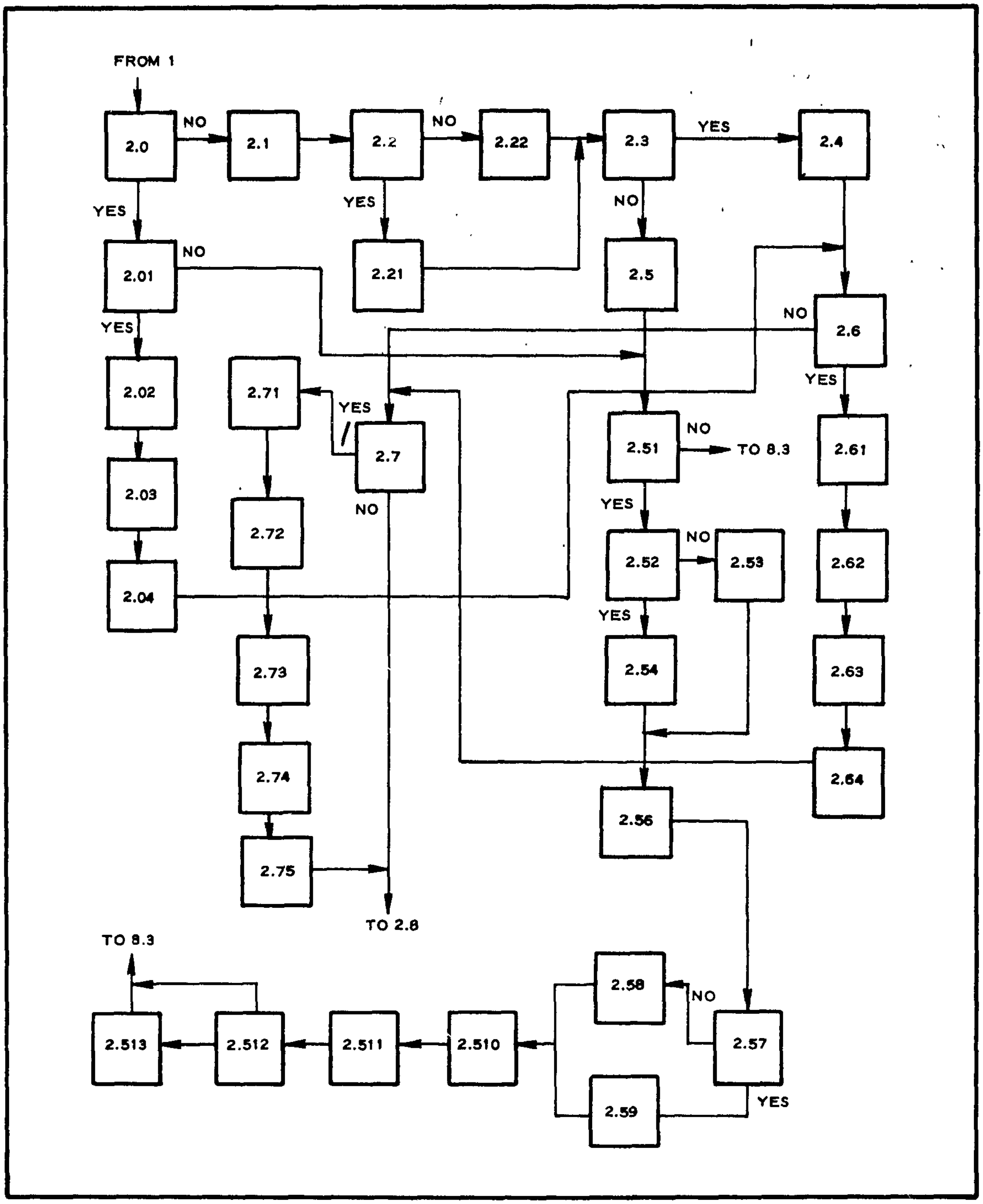

Figure E-6 - Subroutine II Special System Status Conditions

2.0 - Was negative g last iteration?
2.1 - Read and store present g magnitude and direction.
2.01 - Is g positive this iteration?
2.02 - Compute fuel used from negative g tank while in negative g condition.
2.03 - Subtract fuel used in negative g from patron tank volume.
2.04 - Set attitude digit of M.C.W. to 0.
2.2 - Compare: has g changed more than ($G_{n-1} - G_n \leq K_6$) attitude limit?
2.21 - Set attitude bit (M.C.W.) to 1.
2.22 - Set attitude bit (M.C.W.) to 0.
2.3 - Is g positive?
2.4 - Set negative supply rates to 0.
2.5 - Set positive g supply rates to 0.
2.6 - Is a jettison operation scheduled?
2.7 - Is a refueling operation scheduled?
2.71 - Determine that tanks scheduled for refueling can receive fuel.
2.72 - How many tanks can be refueled = N.
2.73 - Compute: tank refueling rate = R_{re}/N and let R_n = single tank input rate.
2.74 - Compute $\Delta V_{re} = R_n \, \Delta T_{it}$.
2.75 - For each tank scheduled for refueling, add ΔV_{re} to tank volume.
2.51 - Is fuel being supplied in normal mode? (or bypass mode)?
2.511 - Insufficient fuel for demand; set output rates to 0.
2.52 - Is patron tank remaining volume $\leq$ negative g volume?
2.53 - Use remaining volume as negative g volume.
2.54 - Use maximum negative g volume as negative g volume.
2.56 - Compute total demand negative g tank.
2.57 - Are booster pumps operational?
2.58 - Use gravity transfer functions.
2.59 - Use booster pump transfer functions.
2.510 - Compute left to negative g tank.
2.511 - Compute new negative g volume.
2.512 - Is negative g volume $\geqq$ 0.
2.513 - Insufficient fuel for engine; set output roles to 0.
2.61 - Determine tank to be jettisoned.
2.62 - Set tank volume to 0.
2.63 - Set transfer function to 0.
2.64 - Disable switch position (input to analog-digital converter.

E. Subroutine III.

Once the initializing logic is completed, the state of the system for this iteration is fixed. The computation of fuel transfer conditions can then proceed. Subroutine III shown in Figure E-7 is designed to determine the total fuel demand on the aircraft fuel systems. The program considers two engineering service tanks. If the aircraft being simulated has only one such tank, the programmer can merely drop the steps devoted to service tank 2. The operations are defined below.

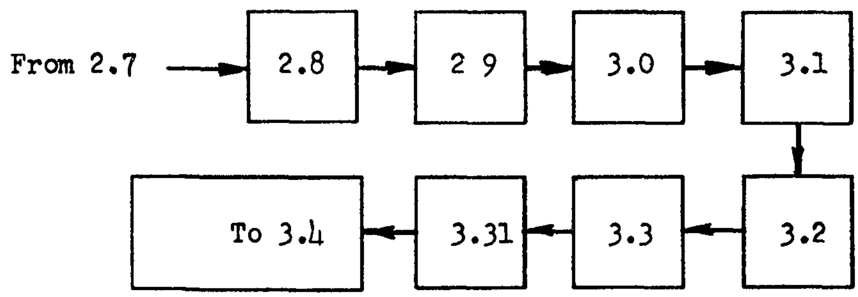

Figure E-7 - Subroutine III for Computing Fuel Demand on Airplane Fuel System

2.8 - Compute engine demand on service tank 1, $R_E = R_{E1} + R_{E2}$, where

R_E = total engine demand rate,
R_{E1} = engine no. 1 demand rate, and
R_{E2} = engine no. 2 demand rate.

2.9 - Compute afterburner demand rate, $R_{A/B} = R_{A/B1} + R_{A/B2}$, where

$R_{A/B}$ = total afterburner demand rate,
$R_{A/B1}$ = afterburner no. 1 demand rate, and
$R_{A/B2}$ = afterburner no. 2 demand rate.

3.0 - Compute total demand on service tank no. 1,
$R_{S.T.1} = R_E + R_{A/B}$, where

$R_{S.T.1}$ = total demand on service tank no. 1.

3.1 - Compute engine demand on service tank no. 2, $R_E = R_{E3} + R_{E4}$, where

R_E = total engine demand rate,
R_{E3} = engine no. 3 demand rate, and
R_{E4} = engine no. 4 demand rate.

3.2 - Compute afterburner demand on service tank no. 2,
$R_{A/B} = R_{A/B3} + R_{A/B4}$, where

$R_{A/B}$ = total afterburner demand rate,
$R_{A/B3}$ = afterburner no. 3 demand rate, and
$R_{A/B4}$ = afterburner no. 4 demand rate.

3.3 - Compute total demand rate on service tank no. 2,
$R_{S.T.2} = R_E + R_{A/B}$, where

$R_{S.T.2}$ = total demand on service tank no. 2.

3.31 - Compute lift between allowable combinations of tank pairs.

F. Subroutine IV.

Subroutine IV (see Figure E-8) begins the computation, by manifolds, of the flow rates of the active lines in the transfer system. The contributing lines to a manifold must have their transfer functions adjusted to reflect the dynamic situation of the aircraft at this instant of time; this is the purpose of the subroutine shown in the figure. The manifold control words that were set up in preceding subroutines are used to determine which lines are active and must be included in the manifold computations. The inactive lines are dropped with their rates set to zero. The IT count is the number of recycles of the current data, up to a given maximum, that are permitted before a new and complete computation of the manifold is undertaken.

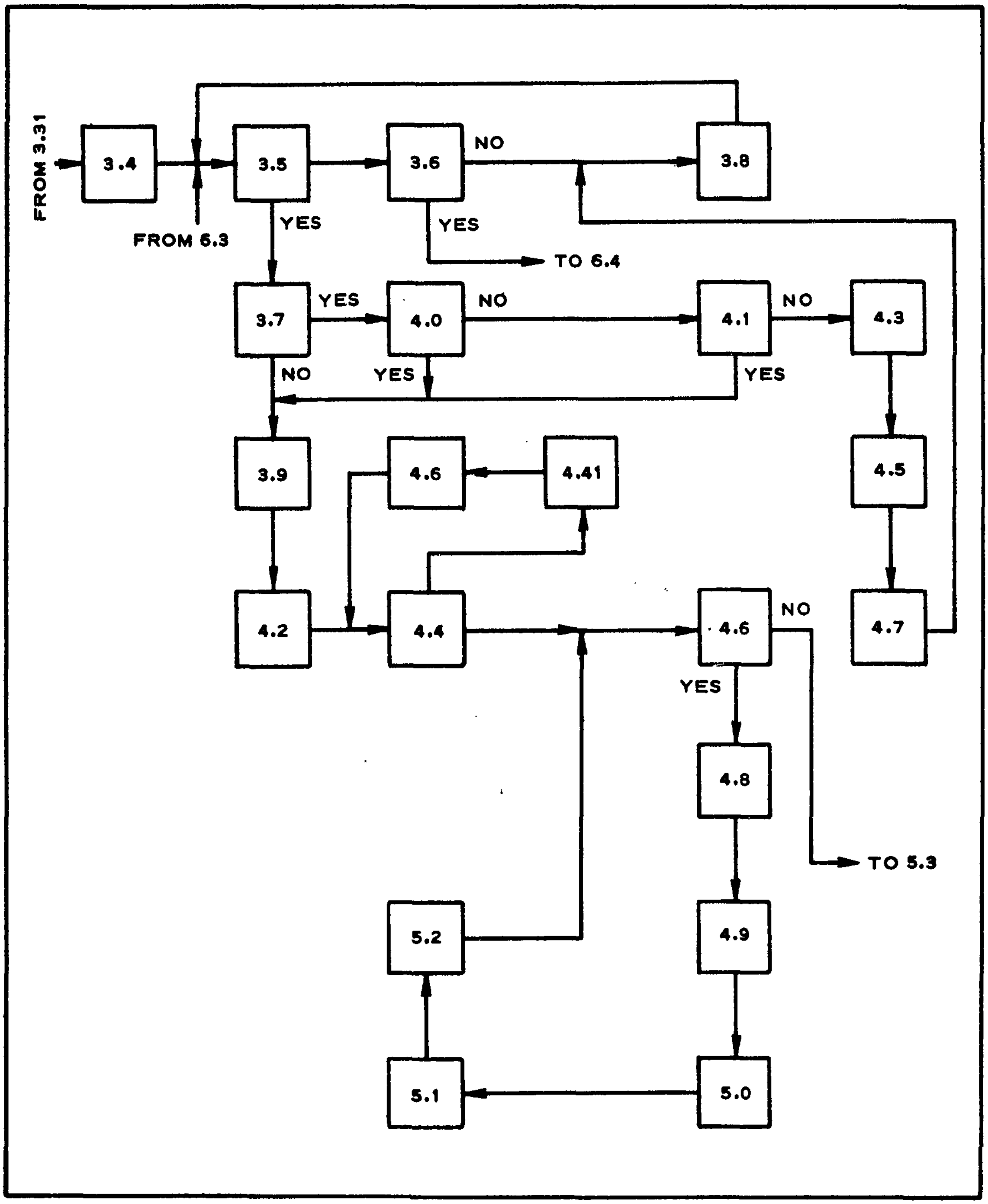

Figure E-8 - Subroutine IV Manifold and Line Transfer Function Adjustment

3.4 - Set manifold counter to $K_{S.T.1}$ = number of manifolds to be computed.
3.5 - Is manifold counter $\geq$ 0?
3.6 - Has service tank no. 2 been computed?
3.7 - For this manifold, compute M.C.W.(n-1) - M.C.W.$_n$ = X; is X = 0?
3.8 - Set manifold count to $K_{S.T.2}$.
3.9 - From M.C.W., determine which lines are enabled to conduct; M lines.
4.0 - Compare: altitude bit $\geq$ 0?
4.1 - Is IT count = 0?
4.2 - Compare: Line conducting conditions = 1?
4.3 - Add -1 to IT count.
4.41 - Add -1 to line count.
4.4 - Set line counter to no. M of conducting lines for this manifold.
4.5 - Store manifold rates from last iteration as those for this iteration.
4.6 - Is counter $\geq$ 0?
4.7 - Add -1 to manifold count.
4.8 - For this line, compute tank pressure difference, $P_i - P_j = \Delta P_{ij}$, where

P_i = Pressure in tank i, and
P_j = Pressure in tank j

4.9 - Compute: $\Delta P_{ij}/w + Z_{ij} = \delta$, where

w = Specific weight of fuel ≈ 0.84, and
Z_{ij} = Head difference due to pressure and lift.

5.0 - Compute: for P_{max} of this line's transfer function,

$P_{max} + \delta = \psi_{max\ ij}$, and
$\psi_{max\ ij}$ = adjusted maximum pressure.

5.1 - Compute: for P_1 of this line's transfer function,

$$P_{1ij} + \delta = \psi_{1ij}.$$

5.2 - Add -1 to counter.

G. Subroutine V.

Subroutine IV adjusted the input line transfer functions for each manifold. Now, Subroutine V, shown in Figure E-9, uses these line transfer functions to determine the total manifold transfer situation in terms of a manifold pressure-rate transfer function. In a later subroutine, a demand rate will be placed on this transfer function and the resulting manifold pressure and the rates of the contributing lines will be easily found.

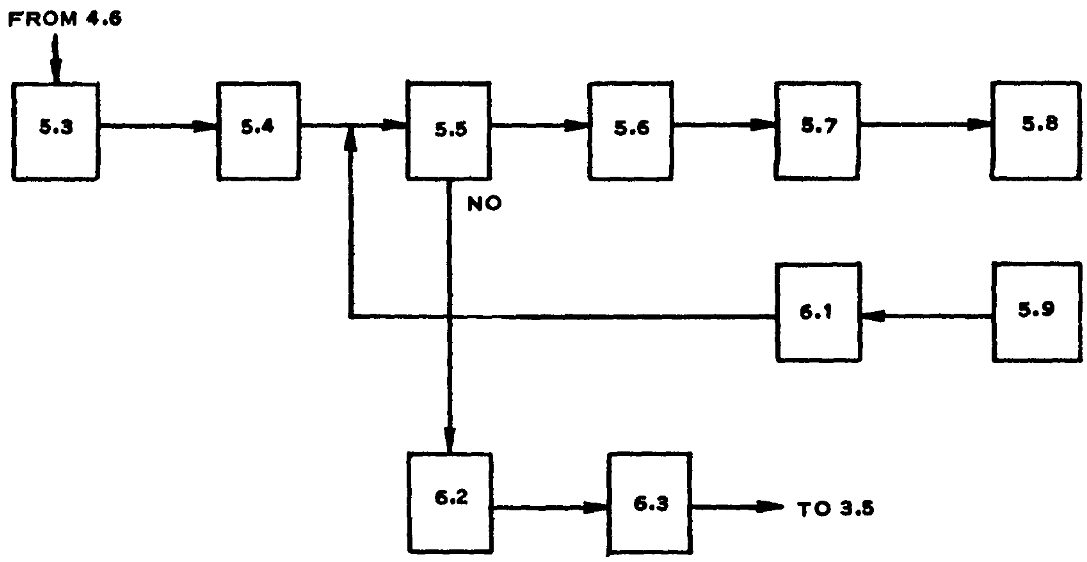

Figure E-9 - Subroutine V for Determining Manifold Flow Conditions

5.3 - For all conducting lines, arrange the $Pmax_{ij}$ and $P1_{kj}$ indescending numerical order. Match ψ_A, ψ_B ... to this sequence. Note that the $\psi_{A,B}$ ..., the $R_{I,II}$ ...; and the $m_{I,II}$ constitute a manifold flow graph.
5.4 - Set counter to = n, the number of terms in 5.3.
5.5 - Is counter $\geq$ 0?
5.6 - Compute: $\psi_A - \psi_B = \Delta\psi_{AB}$.
5.7 - Compute: $\Delta\psi_{AB} \quad m_{ij} = R$.
5.8 - Compute: $R + R_B = R_I$ (this operation will be repeated for each number of 5.3, obtaining the sequence R_I, R_{II}, R_{III} ...).

5.9 - Compute: $m_I = \dfrac{R_I - R_O}{\Delta\psi_{AB}}$ (this operation will be repeated to obtain m_I, m_{II}, ...).

6.1 - Add -1 to n counter.

6.2 - Set IT count to C_{IT}.

6.3 - Add -1 to maximum count.

H. Subroutine VI.

When computing the tank volume, it becomes apparent that the magnitudes of the total input rate and total output rate can produce any one of the following four situations.

1. If the input rate < output rate, the tank volume will be gradually decreased to zero; if it has not reached zero, the incremental volume is subtracted from the total volume.
2. If the input rate < output rate and tank volume is zero, then the output manifold will receive insufficient fuel supply.
3. If the input rate > output rate, the tank will gradually fill up to its maximum volume; if the tank has not reached V_{max}, the incremental volume will be added to tank volume.
4. If the input is > than output and tank volume is maximum, the output rate must equal the input rate.

Subroutine VI, shown in Figure E-10, is designed to rationalize this situation and supply true rates on the effected manifolds.

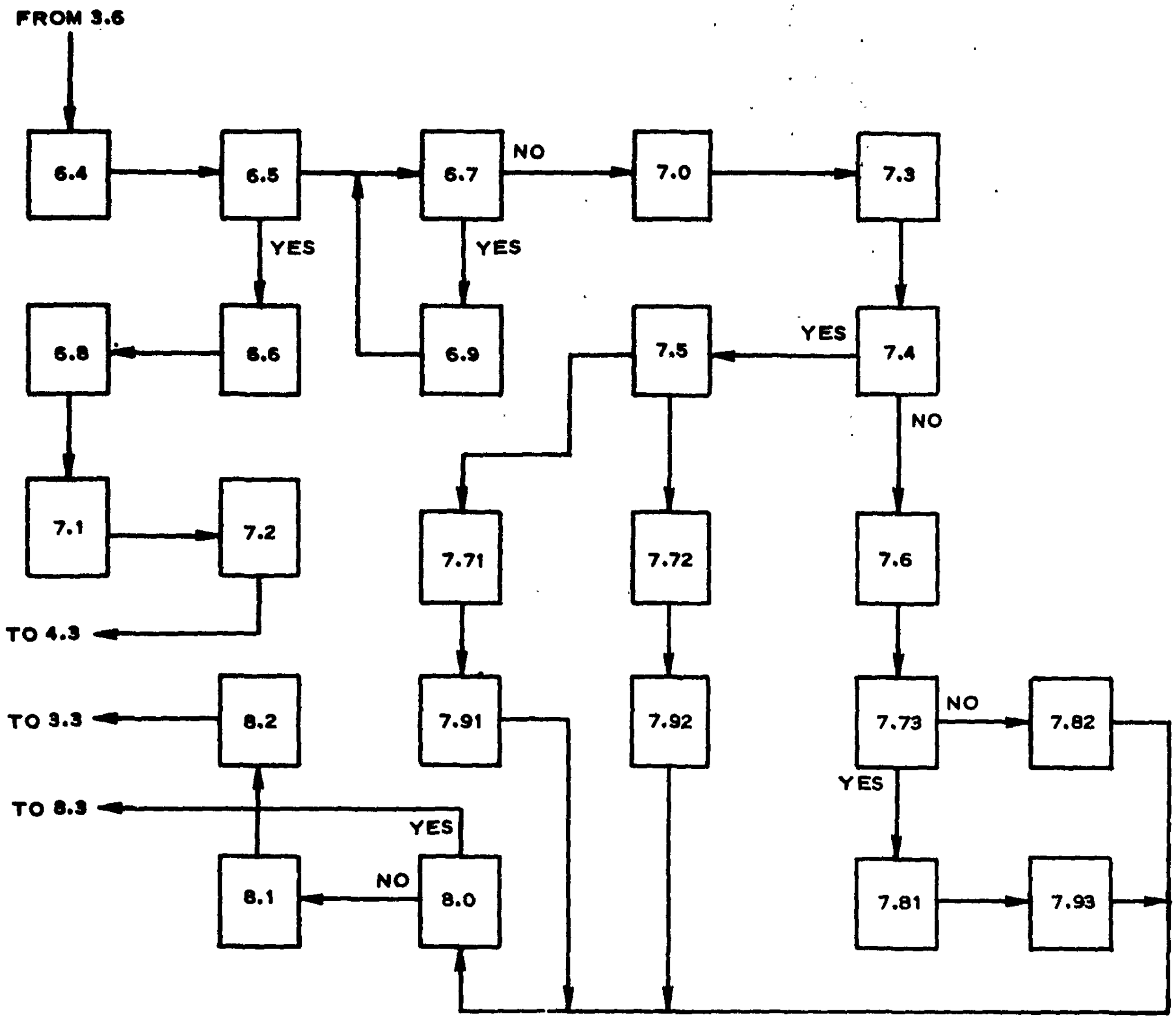

Figure E-10 - Subroutine VI Tank Volume, Input Rate Logic

6.4 - Set counter to n-1.
6.5 - Is $P_{S.T.1} \leq \psi_A$?
6.8 - All transfer for this tank is for ΔV of tank. Compute: input rate = R_V, using tank pressures, lifts, and pump rates.
7.1 - Compute $\Delta V_{S.T.1} = R_V\ (T_{IT})$, where T_{IT} is the iteration time.
7.2 - Add -1 to manifold count.
6.9 - Add -1 to count.
7.0 - Determine available tank input rate = $R_{S.T.1}$, using $\psi_{A,B}$ ... and $m_{I,\ II}$ ... .

7.3 - Compute $R_{S.F.} - R'_{S.F.} = \Delta R_{S.F.}$.
7.4 - Is $\Delta R_{S.F.} > 0$?
7.5 - Is volume $S.F._1 \geq V_{max_{S.F.}}$?
7.6 - Store: $-\Delta R_{S.F.}$.
7.71 - Store: tank $+ \Delta R_{S.F.}$.
7.72 - Set $\Delta R_{S.F.} = 0$.
7.73 - Is volume $S.F._1 \leq 0$?
7.81 - Make $R_{S.F.} = R'_{S.F.}$.
7.82 - Use $R'_{S.F.}$ to find each contributing line rate from manifold flow graph and line transfer functions.
7.91 - Use $R'_{S.F.}$ to determine line input rates.
7.92 - Use manifold flow graph and line transfer functions to determine individual line rates.
7.93 - A limited fuel situation exists.
8.0 - Has service tank no. 2 been computed?
8.1 - Set manual count to the number of lines for service tank 2.
8.2 - Use service tank 2 data for manifold computations.

I. Subroutine VII.

The program up to this point has established the computations necessary to determine rates for all lines in the full transfer schematic. In addition, the increasing or decreasing rates of service tanks have been established. Subroutine VII shown in Figure E-11 will be used to compute the final incremental service tank volumes. It will also compute the incremental volumes of storage tanks by summing input ratio and output rates.

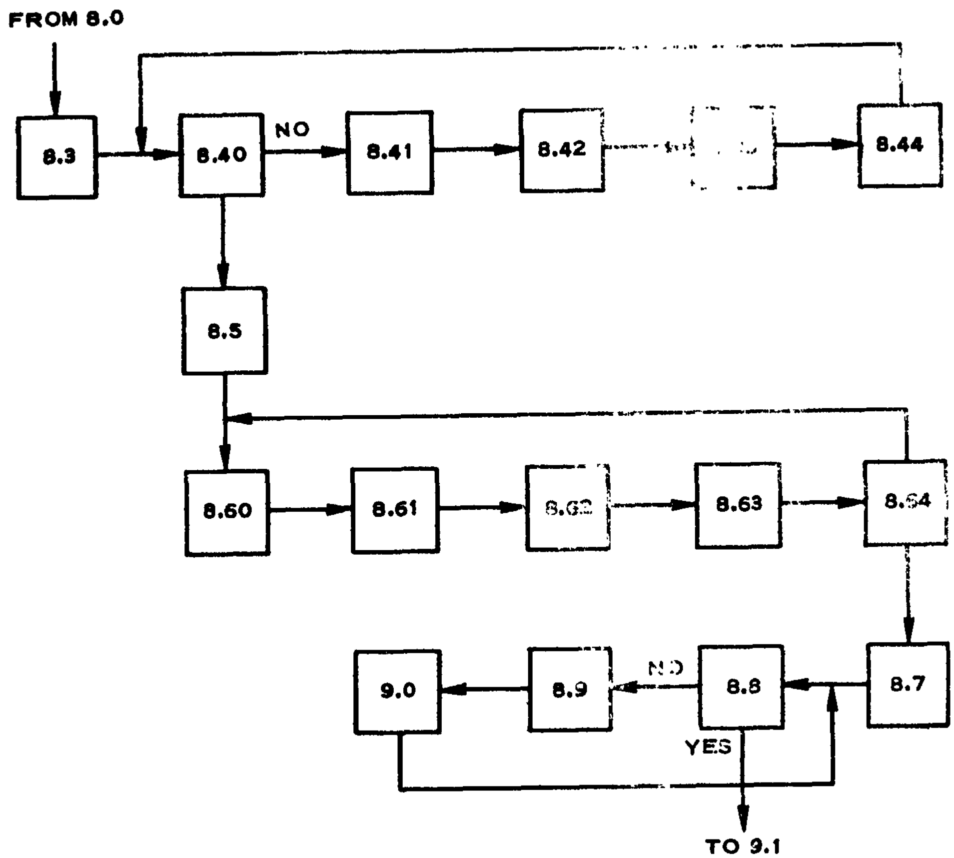

Figure E-11 - Subroutine VII Incremental Volume Computations

8.3 - Set counter to N_I tanks feeding service tank 1.
8.4 - Is N count ≤ 0?
8.41 - For this tank sum the input line rates = R_{in}.
8.42 - For this tank sum the output line rates = R_{out}.
8.44 - Add -1 to count.
8.5 - Set count N_{II} tank feeding service tank 2.
8.6 - Sum input line rates = R_{in}.
8.61 - Sum output line rates = R_{out}.
8.62 - Compute $\Delta V_T = (Rin - R_{out})\, T_{II}$.
8.63 - Add -1 to count.
8.64 - Is count ≤ 0?
8.7 - Set count to the number of tanks.
8.8 - Is count ≤ 0?
8.9 - Add: $\Delta V_1 + \Delta V_2 = \Delta V_T$ for this tank.
9.0 - Add -1 to count.

J. Subroutine VIII.

The subroutine shown in Figure E-12 will be used to compute total tank volumes. The only remaining requirement is that the programmer must arrange readout of the computed information to the appropriate indicators and destinations. The fuel system is sufficiently determined in the computer memory that any desired information can be obtained directly or by the simplest type of computation.

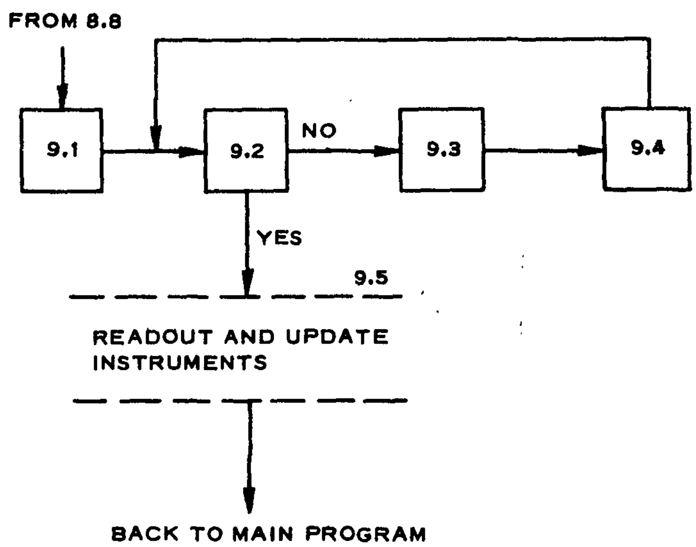

Figure E-12 - Subroutine VIII Total Tank Volume

9.1 - Set count to number of tanks.
9.2 - Is count $\leq$ 0?
9.3 - Compute Δvolume = $\Delta V_T + \Delta V_{(n-1)}$.
9.4 - Add -1 to count.
9.5 - Readout and update instruments and indicators.

SECTION XI. APPENDIX F - DETAILED SIMULATION FLOW CHART FOR GENERAL LANDING GEAR SYSTEM

The flow charts incorporate all the details of logic involved in the simulation. For the simulation of a specific aircraft, it is necessary to go through the flow charts and determine which of the connections, controls, components, etc., apply for that aircraft.

The charts are numbered as follows. First, Subroutines I through V go through the program for a normal "up" command. Then the various alternatives for the "up" signal are checked in Subroutines VI through X, starting at the bottom of Subroutine I and continuing up the chart. Then the normal "down" command is followed through Subroutines X through XII to the point in the program where it rejoins the flow chart for the normal "up" routine at the indicator block. The alternatives for the normal "down" program are then checked in Subroutines XIII through XIV. Subroutine XV is for an "up" command attempted while the plane is on the ground.

The following notation is used in the flow chart:

□ - General program block, branch block, or junction block.

○ - Instructor's light or indicator.

◌ - Pilot's light or indicator.

A. Subroutine I.

Subroutine I establishes the conditions for starting the landing gear system simulation and performs the initial computations necessary for the normal "up" simulation. The flow is charted in Figure F-1, and the operations are defined below.

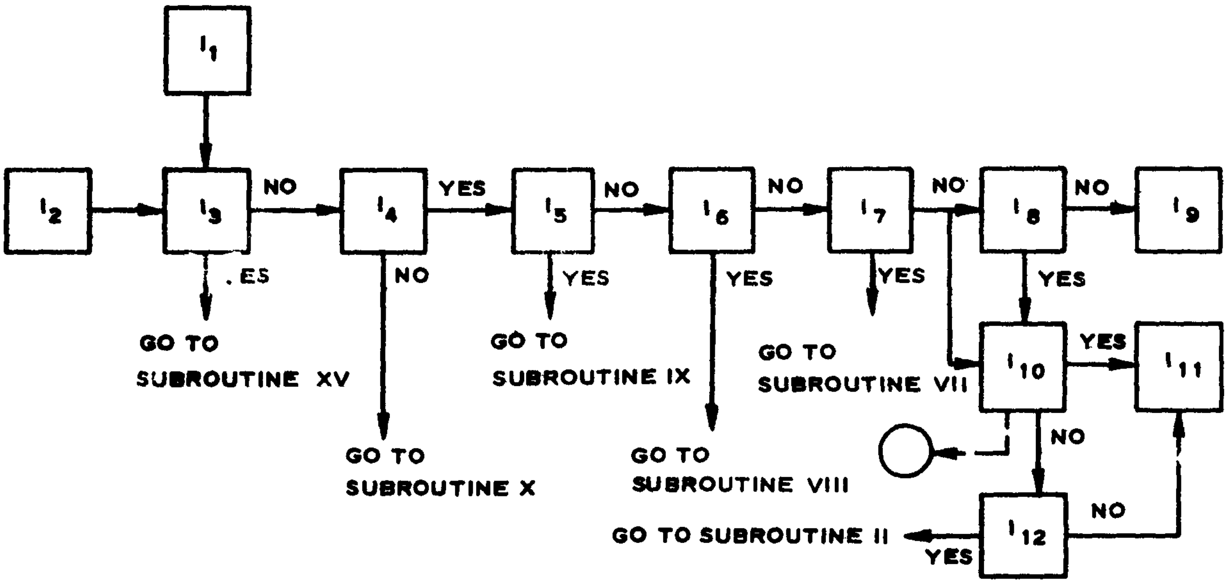

Figure F-1 - Subroutine I for Landing-Gear Simulation

- I_1 - Start landing gear routine.
- I_2 - Input from aerodynamics.
- I_3 - Is aircraft on the ground?
- I_4 - Is normal control lever up?
- I_5 - Is "emergency down" on?
- I_6 - Has "emergency down" been on in last K seconds?
- I_7 - Is "emergency up" on?
- I_8 - Is electrical power available?
- I_9 - No changes, transfer out, landing-gear routine.
- I_{10} - Is landing gear failed down?
- I_{11} - No changes, transfer out.
- I_{12} - Is hydraulic power available?

B. Subroutine II.

Subroutine II checks to determine whether the landing gear has beomce inoperative or limited in operation. It also determines whether the air speed is sufficient to cause an attempted retraction to result in an up and locked landing gear. The flow chart for Subroutine II is given in Figure F-2; the operations are defined below.

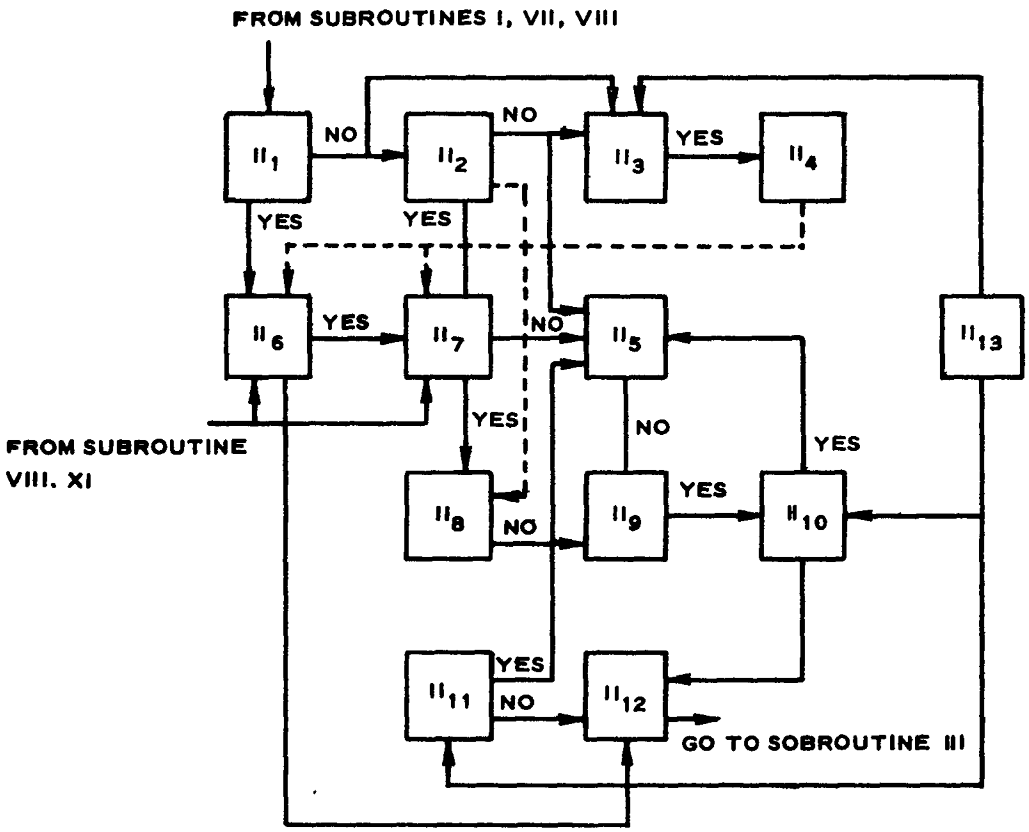

Figure F-2 - Subroutine II for Landing-Gear Simulation

II_1 - Is air speed all right for retraction?
II_2 - Air speed limits gear to transit?
II_3 - Is gear down or in transit?
II_4 - Destroy gear, set aerodynamics, set landing gear inoperative, set hydraulic system, transfer out.
II_5 - No changes, transfer out.
II_6 - Is landing gear limited?
II_7 - Is landing gear operative?
II_8 - Can gear be moved to "transit" only?

II_9 - Can gear be moved up?
II_{10} - Is gear "up"?
II_{11} - Is gear in transit?
II_{12} - Landing-gear computer for retraction.
II_{13} - Landing-gear computer.

C. Subroutine III.

Subroutine III makes the necessary calculations for landing-gear retraction, whether it be normal or emergency operation. The flow is shown in Figure F-3; the operations are defined below.

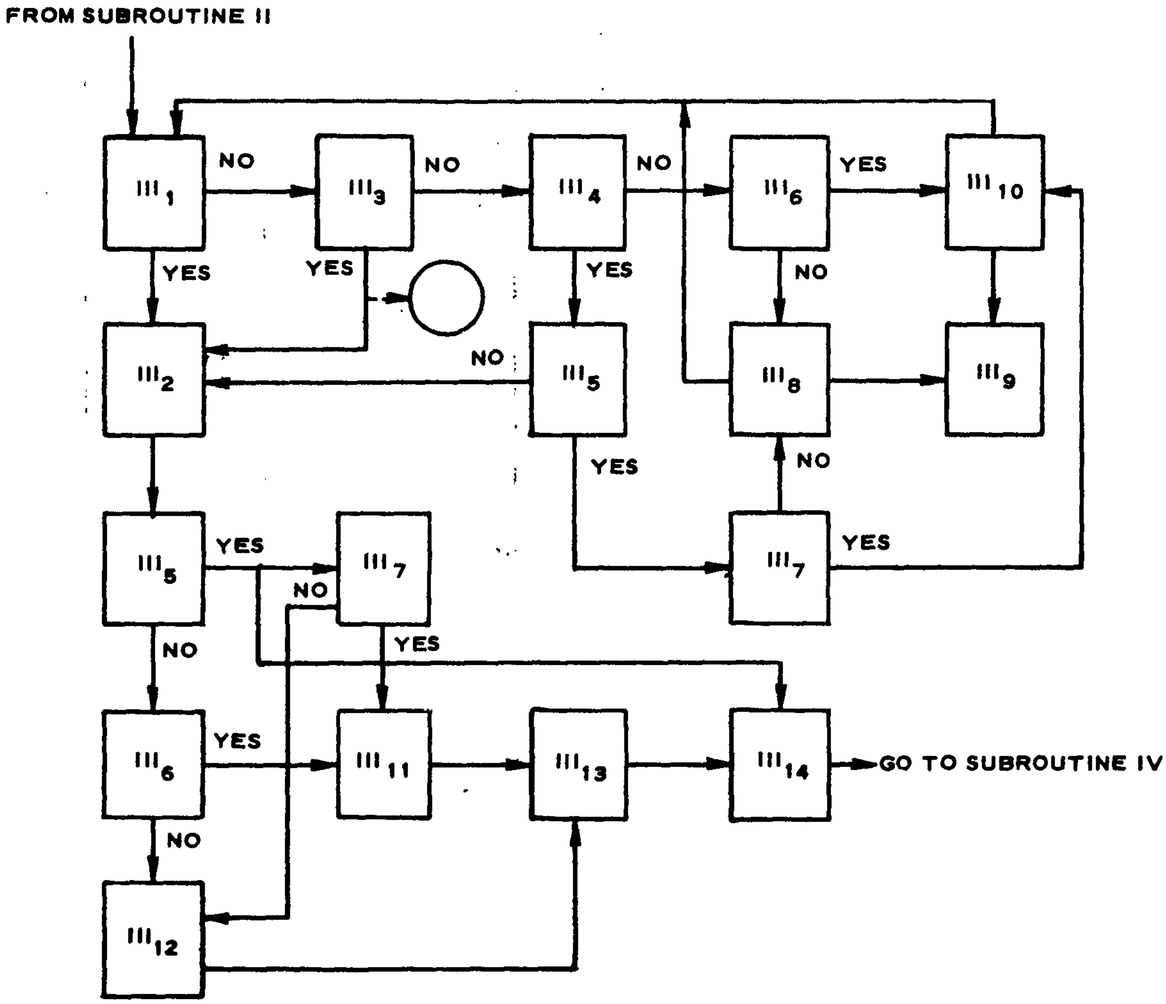

Figure F-3 - Subroutine III for Landing-Gear Simulation

III_1 - Is left gear "up"?
III_2 - Similar programs for right gear and nose gear.
III_3 - Is left gear failed "down and locked"?
III_4 - Is left gear failed "down and released"?
III_5 - Is "emergency up" on?
III_6 - Has it been less than M seconds since normal control to "up"?
III_7 - Has it been less than N seconds since "emergency up" was on?
III_8 - Set left gear "up and locked".
III_9 - Set hydraulic system, aerodynamic indicators, warning light.
III_{10} - Set left gear to IN TRANSIT.
III_{11} - Set tail skid to IN TRANSIT.
III_{12} - Set tail skid to UP.
III_{13} - Set hydraulic system, aerodynamics.
III_{14} - Indicators.

D. Subroutine IV.

Subroutine IV determines whether each gear is "up and locked" or "down and locked." It determines the current location of each gear unless a failure has been inserted. This subroutine is shown schematically in Figure F-4, and the symbols are defined below.

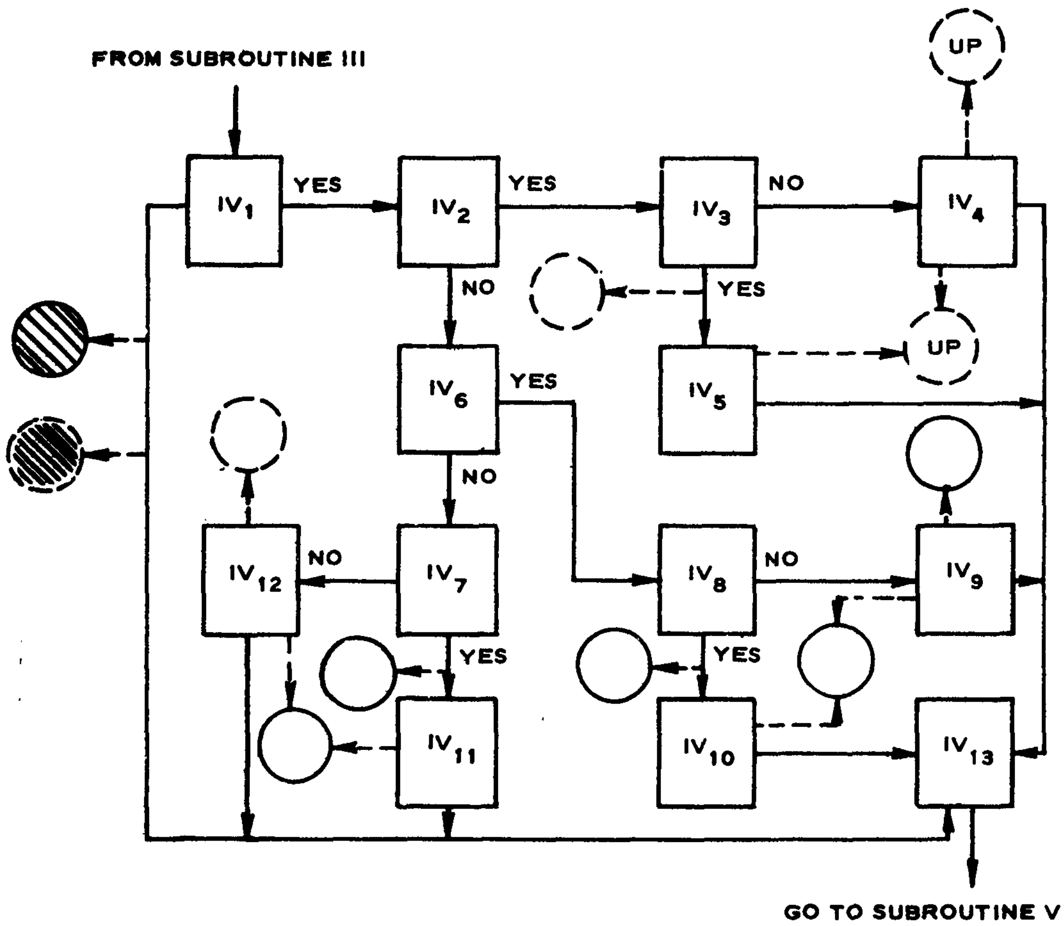

Figure F-4 - Subroutine IV for Landing-Gear Simulation

IV_1 - Is electrical power available?
IV_2 - Is left gear "up and locked"?
IV_3 - Is indicator failed?
IV_4 - Set signal for electrical power.
IV_5 - Set instructor's left gear indicator to UP.
IV_6 - Is left gear "down and locked"?
IV_7 - Is indicator failed?
IV_8 - Is indicator failed?
IV_9 - Set signal for electrical power.
IV_{10} - Set instructor's left gear indicator to DOWN.
IV_{11} - Set instructor's left gear indicator to DOWN.
IV_{12} - Set to TRANSIT.
IV_{13} - Similar programs for right gear and nose gear.

E. Subroutine V

Subroutine V determines whether the landing gear is "unsafe," and checks a variety of situations associated with a landing gear or take-off. The flow for this subroutine is given in Figure F-5, and the operations are defined below.

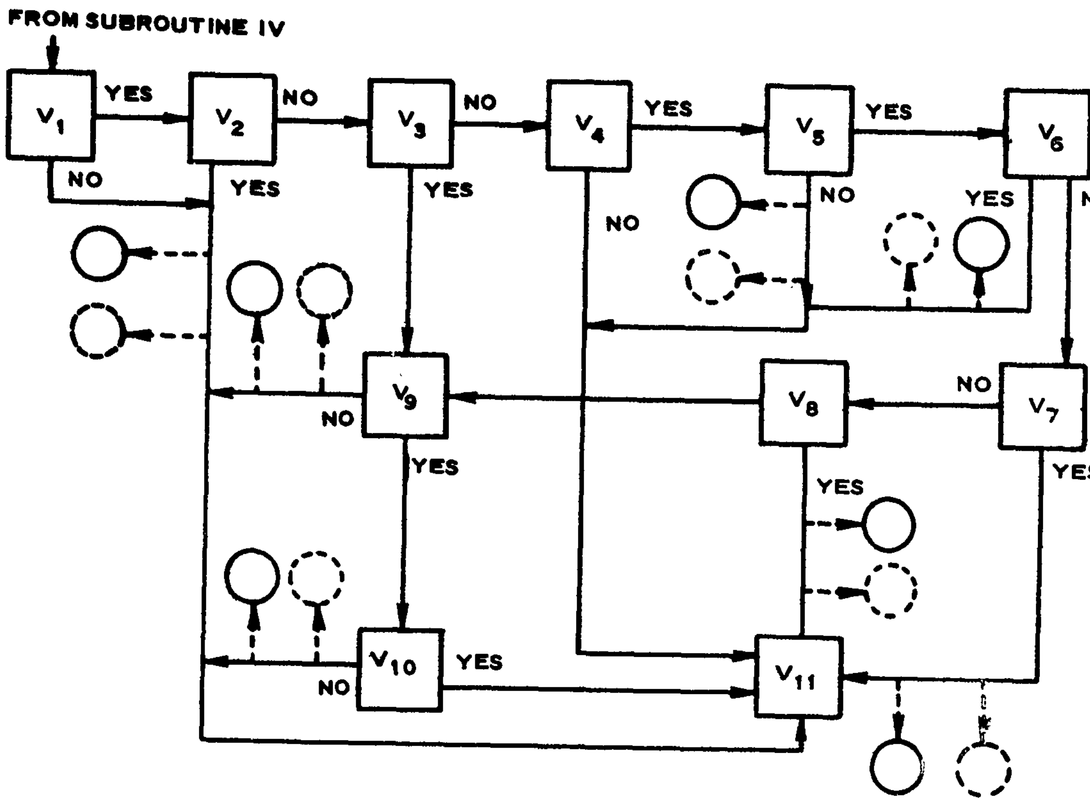

Figure F-5 - Subroutine V for Landing-Gear Simulation

- V_1 - Is electrical power available?
- V_2 - Is any gear in transit?
- V_3 - Is normal control lever "up"?
- V_4 - Is normal lever down or emergency down on?
- V_5 - Are all gear down?
- V_6 - Is altitude less than H?
- V_7 - Is air speed less than X?
- V_8 - Is throttle to idle retarded?
- V_9 - Are flaps up?
- V_{10} - Is arresting gear up?
- V_{11} - Transfer out.

F. Subroutine VI.

Subroutine VI determines whether electrical power is available for landing-gear operation and pilot action in case the circuit breaker is open. Subroutine VI is shown schematically in Figure F-6, and the operations are defined below.

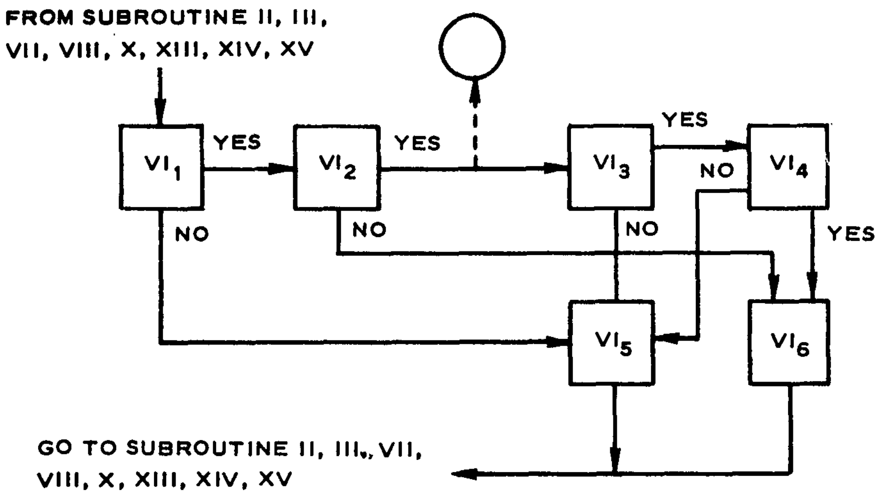

Figure F-6 - Subroutine VI for Landing Gear Simulation

VI_1 - Is electrical power available?
VI_2 - Is circuit breaker open?
VI_3 - Can pilot close circuit breaker?
VI_4 - Did pilot close circuit breaker?
VI_5 - Power available.
VI_6 - No power available.

G. Subroutine VII.

For a normal and emergency up condition of the landing gear, Subroutine VII determines whether electrical and hydraulic power are available for landing-gear operation. Figure F-7 shows the flow diagram, and the operations are defined below.

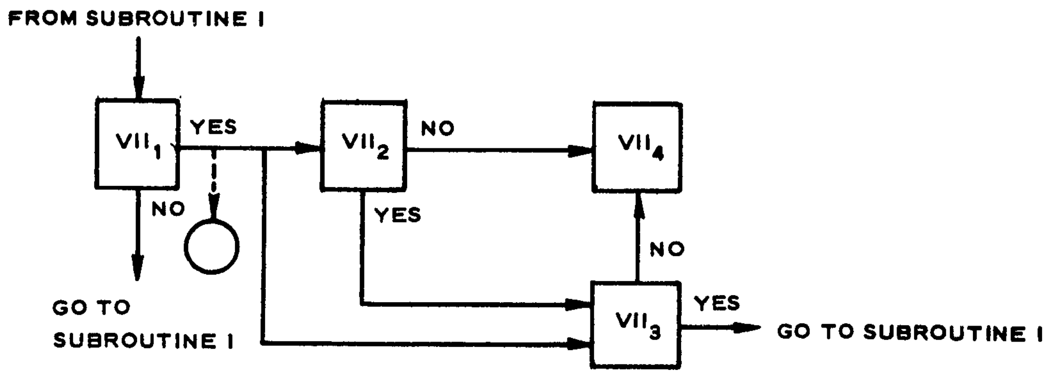

Figure F-7 - Subroutine VII of Landing-Gear Simulation

VII_1 - Is "emergency up" on?
VII_2 - Is electrical power available?
VII_3 - Is hydraulic power available?
VII_4 - No changes, transfer out.

. Subroutine VIII.

Subroutine VIII performs the necessary calculations for retractions in which "normal" or "emergency up" and "emergency down" have been on within the last K seconds. Figure F-8 is the flow diagram; the operations are defined below.

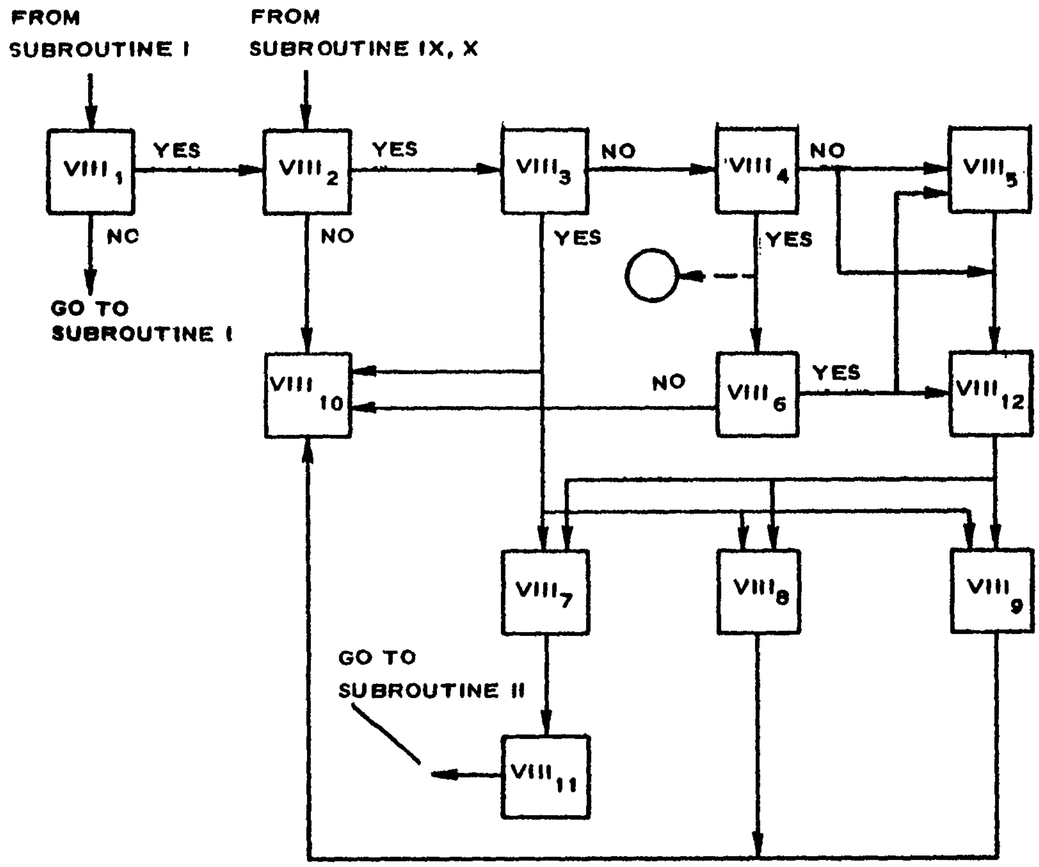

Figure F-8 - Subroutine VIII for Landing-Gear Simulation

$VIII_1$ - Has "emergency down" been within last K seconds?
$VIII_2$ - Is hydraulic power available?
$VIII_3$ - Has hydraulic power been available less than Q seconds since "emergency down"?
$VIII_4$ - Is landing gear failed "down"?
$VIII_5$ - Is electrical power available?
$VIII_6$ - Is "emergency up" on?
$VIII_7$ - Set landing gear limited to "up" or "down" or "in transit."
$VIII_8$ - Set hydraulic system inoperative.
$VIII_9$ - Set landing gear inoperative.
$VIII_{10}$ - No changes, transfer out.
$VIII_{11}$ - Air speed all right, landing gear operative, check for retraction.
$VIII_{12}$ - Junction.

I. Subroutine IX.

With the normal control up while the "emergency down" is on, Subroutine IX checks the circuit breaker prior to landing-gear extensions. Figure F-9 is the flow diagram, and the operations are defined below.

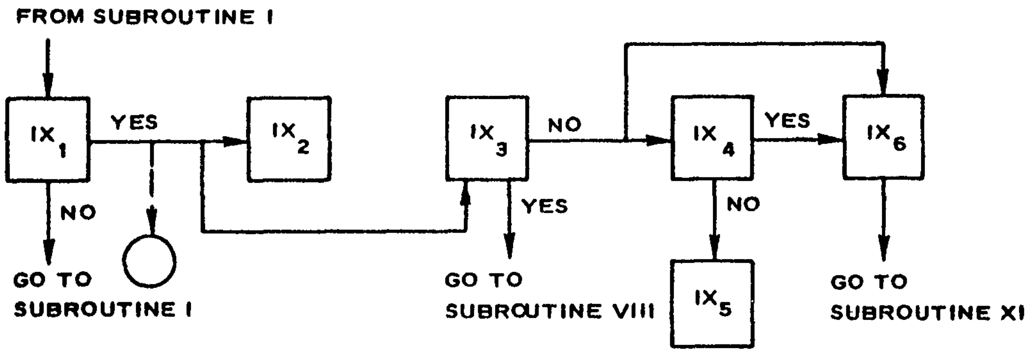

Figure F-9 - Subroutine IX for Landing-Gear Simulation

IX_1 - Is "emergency down" on?
IX_2 - No changes, transfer out.
IX_3 - Is "emergency up" on?
IX_4 - Is circuit breaker off?
IX_5 - Trouble, transfer out.
IX_6 - Air speed all right, landing-gear operative, check for extension.

J. Subroutine X.

Subroutine X determines whether electrical and hydraulic power are available, with the normal control lever down. The flow diagram is presented in Figure F-10, while the operations are defined below.

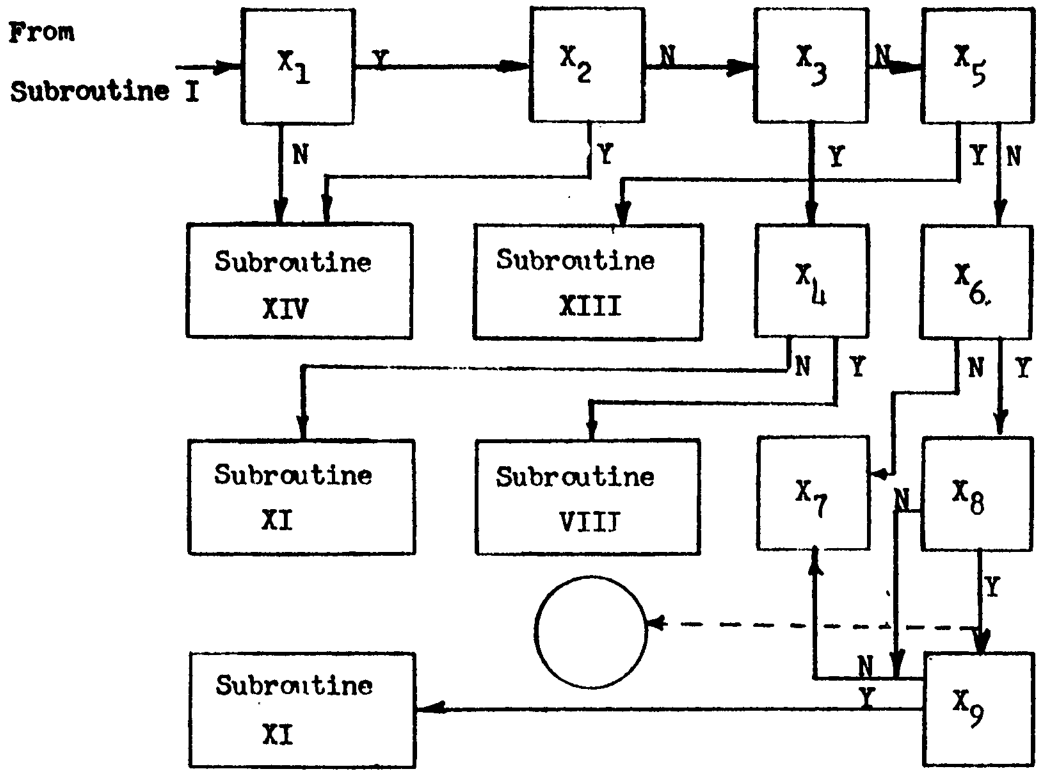

Figure F-10 - Subroutine X for Landing-Gear Simulation

X_1 - Is normal control lever down?
X_2 - Is "emergency down" on?
X_3 - Has "emergency down" been on within last K seconds?
X_4 — Has "gear up" been tried?
X_5 - Is "emergency up" on?
X_6 - Is electrical power available?
X_7 - No changes, transfer out.
X_8 - Is landing gear failed "up"?
X_9 - Is hydraulic power available?

K. Subroutine XI.

Subroutine XI determines whether the landing gear is to be extended and establishes the necessary conditions. Figure F-11 is the flow chart; the operations are defined below.

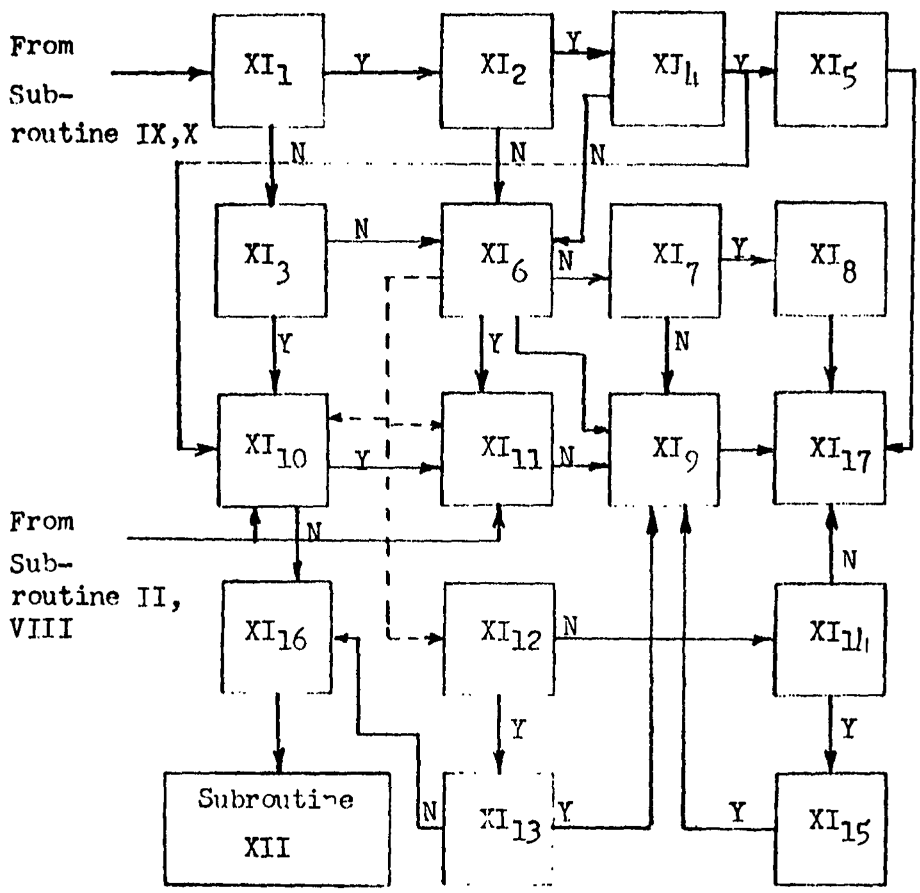

Figure F-11 - Subroutine XI for Landing-Gear Simulation

XI_1 - Is "emergency down" on?
XI_2 - Is air speed all right for "emergency down"?
XI_3 - Is air speed all right for "normal down"?
XI_4 - Is pneumatic power available?
XI_5 - Set pneumatic system.
XI_6 - Can gear move to in transit only?
XI_7 - Is gear down or in transit?
XI_8 - Destroy gear, set aerodynamics, set landing gear inoperative, set hydraulic system.
XI_9 - No changes.
XI_{10} - Is landing gear limited?

XI_{11} - Is landing gear operative?
XI_{12} - Can gear move to in transit only?
XI_{13} - Is gear in transit?
XI_{14} - Can gear move to "down"?
XI_{15} - Is gear "down"?
XI_{16} - Landing gear extension computer.
XI_{17} - Transfer out.

L. Subroutine XII.

Subroutine XII makes the necessary calculations for landing-gear extension. The flow diagram is presented in Figure F-12 and the symbols are defined below.

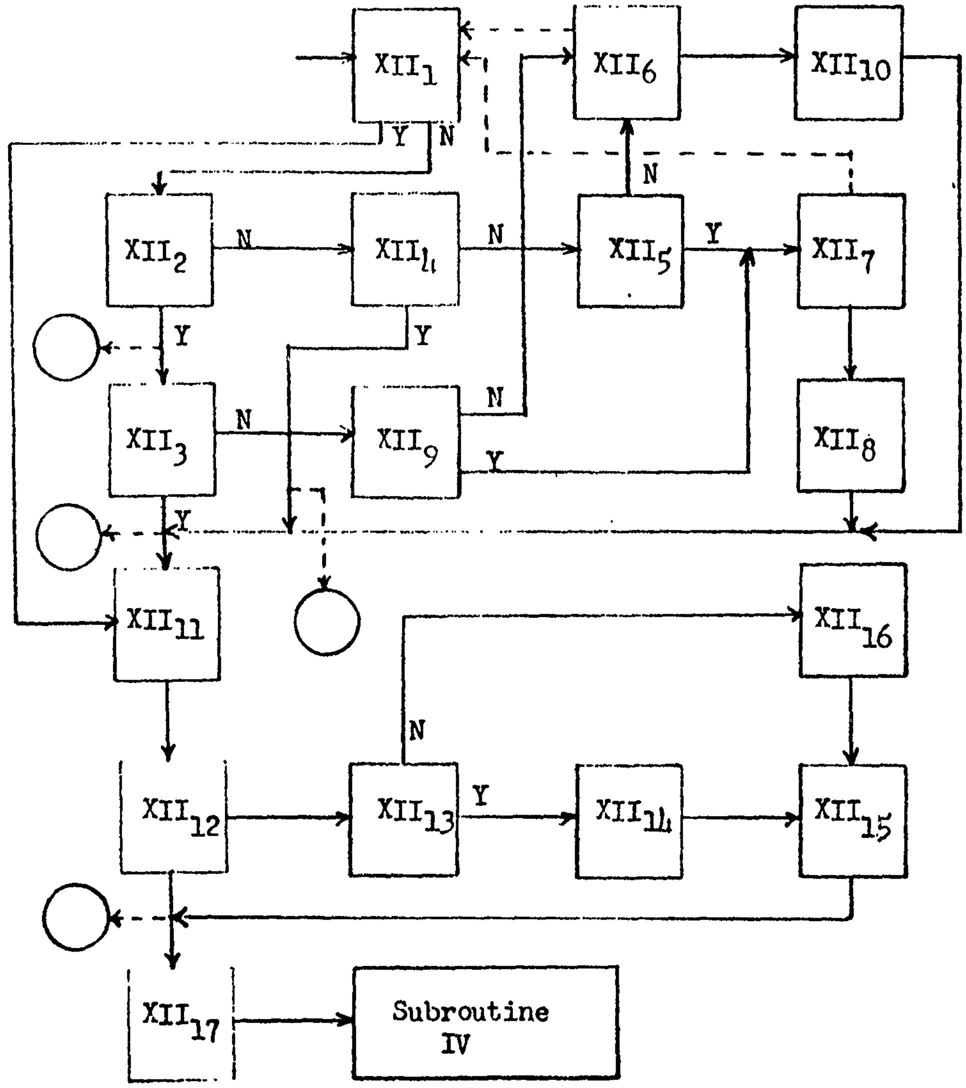

Figure F-12 - Subroutine XII for Landing-Gear Simulation

XII_1 - Is left gear "down"?
XII_2 - Is "emergency down" on?
XII_3 - Is left gear failed "up"?
XII_4 - Is left gear failed "up" or failed and released?
XII_5 - Is it less than M seconds since normal control to "down"?
XII_6 - Set left gear to "down and locked."

XII$_7$ - Set left gear "in transit".
XII$_8$ - Set hydraulic system, aerodynamic indicators, warning lights.
XII$_9$ - Is it less than N seconds since "emergency down"?
XII$_{10}$ - Set pneumatic system, aerodynamic indicators, warning lights.
XII$_{11}$ - Similar programs for right gear and nose gear.
XII$_{12}$ - Is "emergency down" on?
XII$_{13}$ - Is it less than N seconds since normal control to "down"?
XII$_{14}$ - Set tail skid to "in transit".
XII$_{15}$ - Set hydraulic system, aerodynamics.
XII$_{16}$ - Set tail skid to "down and locked".
XII$_{17}$ - Indicators.

M. Subroutine XIII.

Subroutine XIII determines the availability of electrical and hydraulic power for landing-gear retraction, with the normal control lever "down" and "emergency up" on. Figure F-13 is the flow diagram, with the operations defined below.

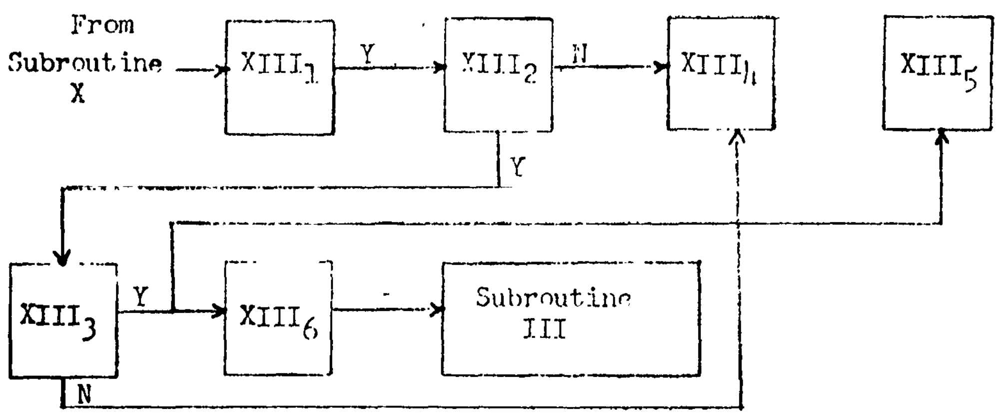

Figure F-13 - Subroutine XIII for Landing-Gear Simulation

XIII$_1$ - Is "emergency up" on?
XIII$_2$ - Is electrical power available?
XIII$_3$ - Is hydraulic power available?
XIII$_4$ - No changes, transfer out.
XIII$_5$ - Set landing gear inoperative, transfer out.
XIII$_6$ - Landing-gear retraction computer.

N. Subroutine XIV.

Subroutine XIV checks the circuit breaker for landing gear extension, with "emergency down" on. The flow diagram is presented in Figure F-14; the operations are defined below.

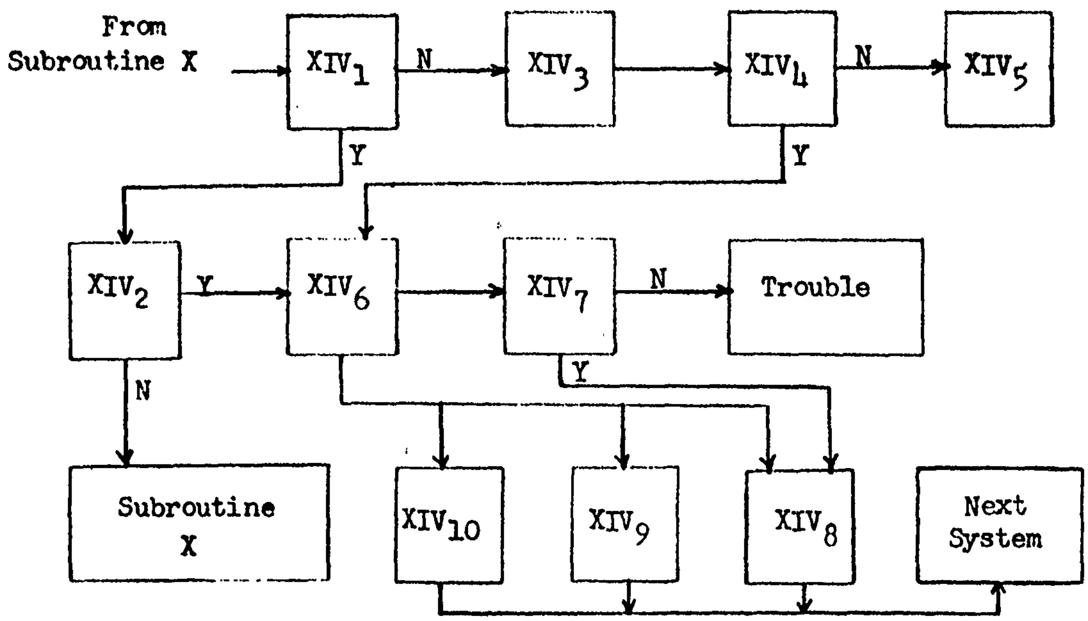

Figure F-14 - Subroutine XIV for Landing-Gear Simulation

XIV_1 - Is normal control lever "down"?
XIV_2 - Is "emergency down" on?
XIV_3 - Normal control out, is emergency down?
XIV_4 - Was normal control down then out?
XIV_5 - No changes, transfer out?
XIV_6 - Junction.
XIV_7 - Is circuit breaker off?
XIV_8 - Air speed all right, landing-gear operative, check for extensions.
XIV_9 - Set flaps inoperative.
XIV_{10} - Set hydraulic system (dump fluid).

O. Subroutine XV

Subroutine XV checks electrical and hydraulic power availability for a "normal" or "emergency up" command while the aircraft is on the ground. Figure F-15 is the flow diagram; the operations are defined below.

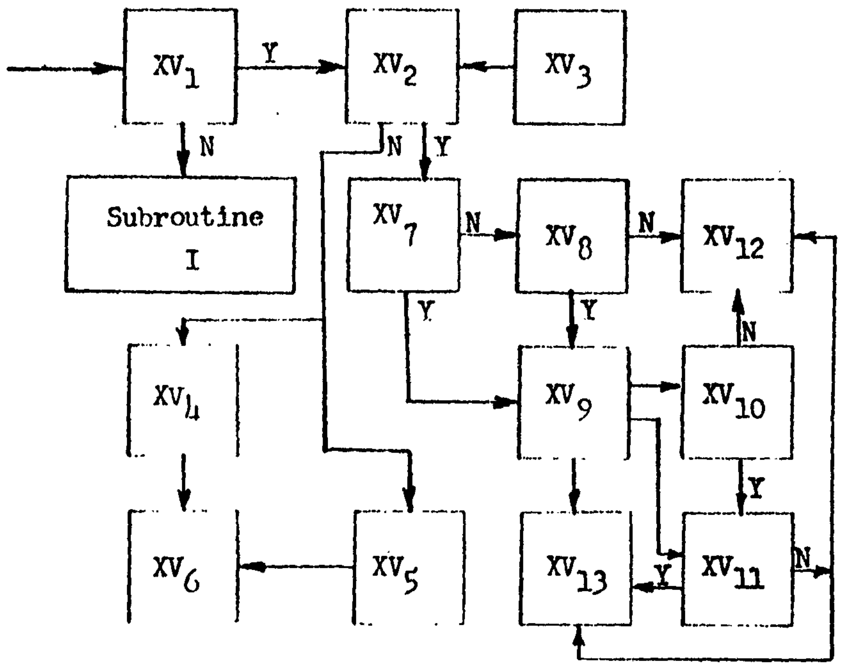

Figure F-15 - Subroutine XV for Landing-Gear Simulation

XV_1 - Is airplane on ground.
XV_2 - Is safety switch released?
XV_3 - "Emergency up" release (pilot).
XV_4 - "Normal" control lever immovable.
XV_5 - No change for "normal" control "up".
XV_6 - Transfer out.
XV_7 - Is "normal" control lever up?
XV_8 - Is "emergency up" control on?
XV_9 - Junction.
XV_{10} - Is electrical power available?
XV_{11} - Is hydraulic power available?
XV_{12} - No changes, transfer out.
XV_{13} - Crash.

SECTION XII. APPENDIX G - DETAILED SIMULATION FLOW CHART FOR ELECTRICAL SYSTEM

A. Subroutine I.

Subroutine I determines whether internal or external power is used in the simulation. Figure G-1 is the flow diagram; the operations are defined below.

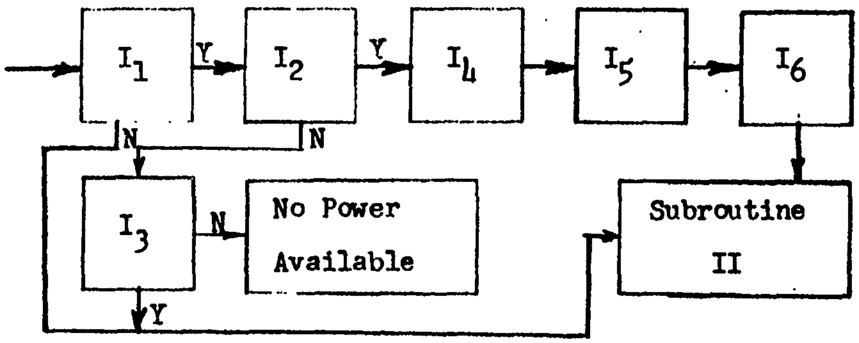

Figure G-1 - Subroutine I for Electrical System Simulation

- I_1 - Is pilot's INTERNAL-EXTERNAL power switch on EXTERNAL or absent? If this switch is present, the pilot can indicate the type of power he needs.
- I_2 - Is instructor external power supply switch turned to ON? (This is an on-off switch to determine if external power is available.)
- I_3 - Is pilot's INTERNAL-EXTERNAL power switch absent?
- I_4 - Determine loads required for external power condition.
- I_5 - Have conditions been fulfilled for take-off?
- I_6 - Instructor-set external power supply switch turned to OFF.

B. Subroutine II.

Subroutine II determines what system is to be used in the simulation. The flow diagram is given in Figure G-2, and the operations are defined below.

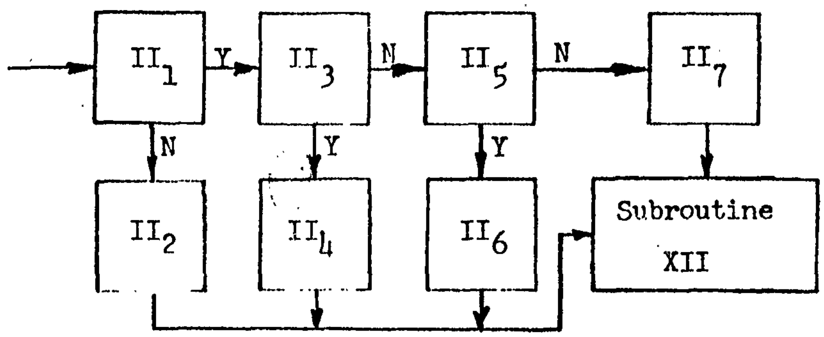

Figure G-2 - Subroutine II for Electrical System Simulation

II_1 - Is a-c generator present? Test to determine the presence of an a-c generator.

II_2 - Only d-c generator present; a-c generator is not present. D-C generator is present. Simulation beginning here is a single d-c generator system.

II_3 - Is d-c generator present? Test to determine the presence of a d-c generator.

II_4 - An a-c and d-c generator are present. The simulation of an a-c and d-c generator system follows.

II_5 - Is a second a-c generator present? Test to determine the presence of a second a-c generator.

II_6 - Two a-c generators are present. The simulation of a double a-c generator system follows.

II_7 - A single a-c generator is present. The simulation of a single a-c generator system follows.

C. Subroutine III.

Subroutine III determines pilot action in case of a generator overvoltage. Figure G-3 is the flow chart; the operations are defined below.

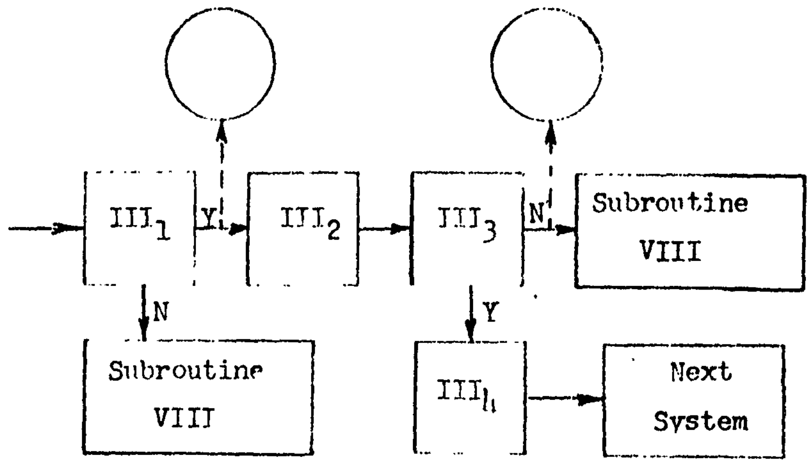

Figure G-3 - Subroutine III for Electrical System Simulation

III_1 - Is instructor's overvoltage switch on? The instructor may cut out the d-c generator temporarily.

III_2 - Pilot-set generator reset switch set to RESET. The instructor's overvoltage switch is set to ON. Pilot attempts to bring the generator back on the line with this reset procedure. The switch is spring-loaded back to NORMAL.

III_3 - Has pilot reset procedure restored the generator? If voltage has dropped below 32 v, pilot reset procedure will cause the generator to cut in.

III_4 - Compute normal load requirements. The instructor has inserted no failures. Total normal load requirements can be computed, as obtained from the aircraft flight handbook.

D. Subroutine IV.

Subroutine IV determines the condition of the inverters for supplying a-c power. The flow diagram is presented in Figure G-4, while the operations are defined below.

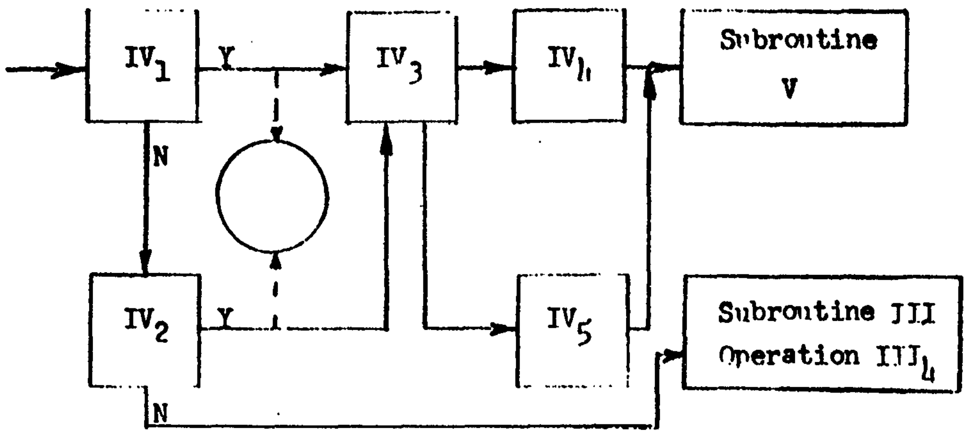

Figure G-4 - Subroutine IV for Electrical System Simulation

IV_1 - Is instructor's inverter no. 1 fail switch on? Test instructor's inverter fail switch position.

IV_2 - Is instructor's inverter no. 2 fail switch on? Test instructor's inverter no. 2 fail switch position.

IV_3 - Pilot sets instrument power switch set to no. 2 inverter position. The instructor has failed either the no. 1 or no. 2 inverter. The pilot sets the instrument power switch to no. 2 inverter position in either case.

IV_4 - Compute loads associated with no. 1 inverter failure. These loads can be obtained from the aircraft flight handbook for the no. 1 inverter failure.

IV_5 - Compute loads associated with no. 2 inverter failure. These loads can be obtained from the aircraft flight handbook for the no. 2 inverter failure.

E. Subroutine V.

Subroutine V determines pilot action in event of a d-c generator failure in a single d-c generator system. Figure E-5 is the flow diagram; the operations are defined below.

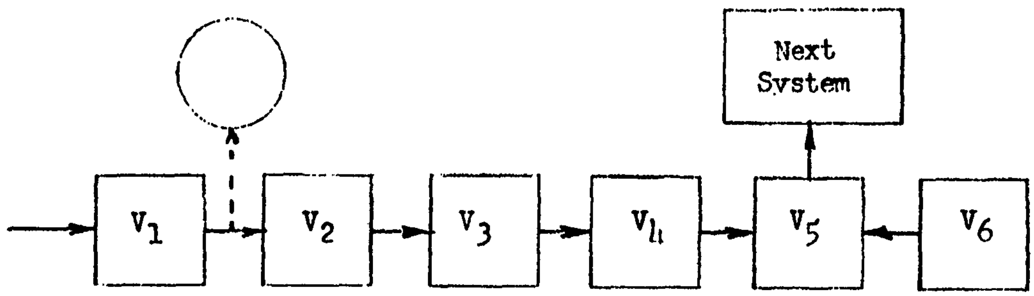

Figure G-5 - Subroutine V of Electrical System Simulation

V_1 - Instructor's d-c generator fail switch is on. The instructor has failed the d-c generator.

V_2 - Pilot sets the battery-generator switch to OFF and BATTERY-GENERATOR. This procedure cuts out the generator and connects the battery.

V_3 - Pilot turns off all nonessential equipment, which reduces the loads on the battery.

V_4 - Compute emergency load requirements. These are the loads associated with emergency operation and can be obtained from the flight handbook.

V_5 - Start landing operation. Landing operation should begin as soon as possible after emergency conditions are set.

V_6 - Input from hydraulic system.

F. Subroutine VI.

Subroutine VI determines the condition of the a-c generator in a single a-c generator system. The flow diagram is presented in Figure G-6, and the operations are defined below.

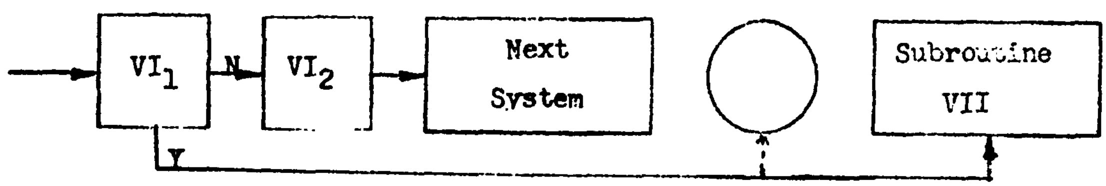

Figure G-6 - Subroutine VI of Electrical System Simulation

VI_1 - Is instructor's a-c generator fail switch on? Test the instructor's a-c generator fail switch position.

VI_2 - Compute the normal load requirements of a single a-c generator system.

G. Subroutine VII.

Subroutine VII brings the air speed within the proper limit for emergency operation. Figure G-7 is the flow diagram; the operations are defined below.

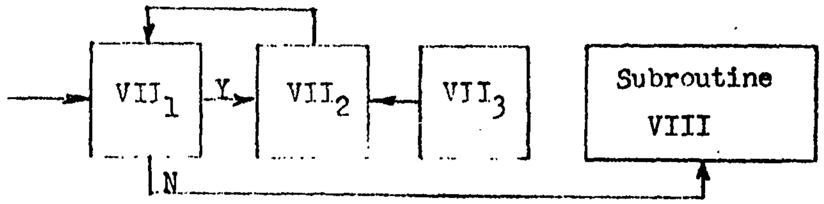

Figure G-7 - Subroutine VII of Electrical System Simulation

VII_1 - Is air speed above 500 knots? Emergency power is required, but should not be released if air speed is above 500 knots to prevent damage to the generator.

VII_2 - Pilot initiates procedure to reduce air speed below 500 knots.

VII_3 - Input from aerodynamics to reduce air speed.

H. Subroutine VIII.

Subroutine VIII determines pilot action for emergency operation, as shown schematically in Figure G-8. The operations are defined below.

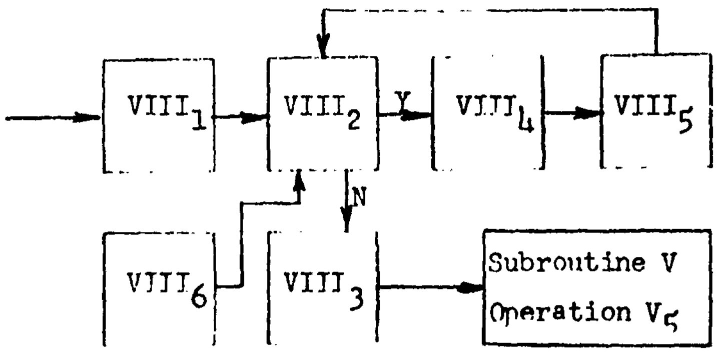

Figure G-8 - Subroutine VIII for Electrical System Simulation

VIII$_1$ - Pilot releases emergency power. With airspeed below 500 knots, the pilot can now release emergency power.

VIII$_2$ - Is power needed to adjust the horizontal stabilizer? The horizontal stabilizer might need some adjustment to maintain control of the aircraft.

VIII$_3$ - Compute emergency load requirements for a single a-c generator system.

VIII$_4$ - Pilot actuates horizontal stabilizer manual override switch, which releases power to the horizontal stabilizer.

VIII$_5$ - All emergency power on to horizontal stabilizer except 366 va. All emergency power is utilized by the horizontal stabilizer except the 366 va needed for cockpit lights, gyro horizon, cabin temperature control, nesa glass, and warning-light relays.

VIII$_6$ - Input from aerodynamics.

I. Subroutine IX.

Subroutine IX determines the condition of the d-c generator in a d-c and a-c generator system. The flow chart is presented in Figure G-9, while the operations are defined below.

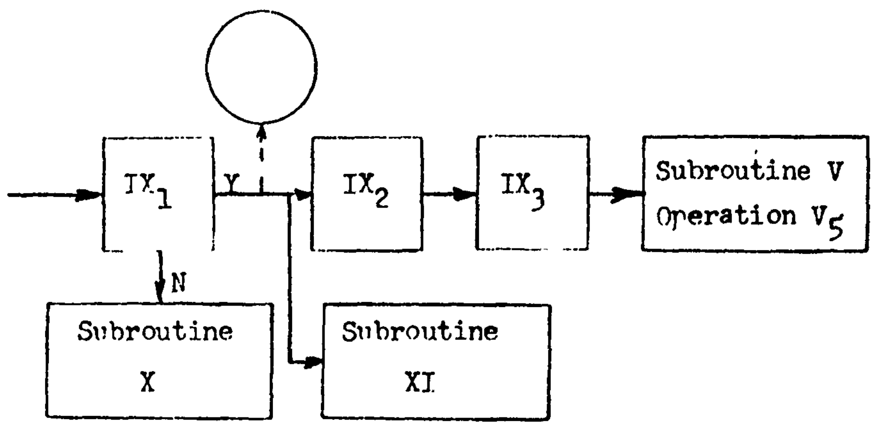

Figure G-9 - Subroutine IX for Electrical System Simulation

IX$_1$ - Is instructor's d-c generator fail switch on? Test instructor's fail switch position associated with d-c generator.

IX$_2$ - Pilot sets a-c power switch to GENERATOR position. The instructor has inserted a d-c generator failure. Necessary d-c power is provided by the a-c generator through a transformer.

IX$_3$ - Compute loads associated with d-c generator failure for a d-c and a-c gener[illegible] system. These are the

required a-c loads and also the necessary d-c load supplied by the a-c generator through the transformer.

J. Subroutine X.

Subroutine X determines the condition of the a-c generator in a d-c and a-c generator system. The flow chart is presented in Figure C-10, and the operations are defined below.

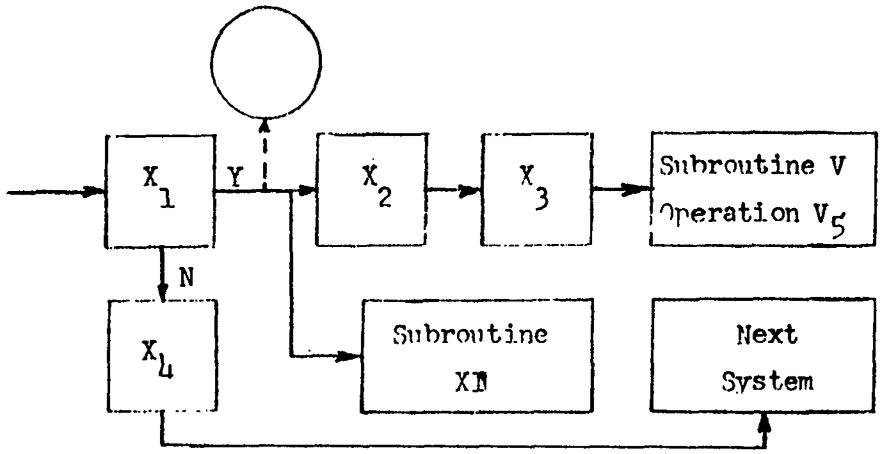

Figure C-10 - Subroutine X for Electrical System Simulation

X_1 - Is instructor's a-c generator fail switch on? Test instructor's fail switch position associated with a-c generator.

X_2 - Pilot set a-c power switch to INVERTER position. The instructor has inserted an a-c generator failure. The inverter, energized by d-c power, supplies the essential power.

X_3 - Compute loads associated with a-c generator failure for a d-c and a-c generator system. These are the required d-c loads and the necessary a-c loads supplied by the inverter.

X_4 - Compute normal load requirements for a d-c and a-c generator system. No generator failures have occurred.

K. Subroutine XI.

Subroutine XI determines the pilot's action in case both generators in a d-c and a-c generator system fail. Figure G-11 is the flow chart; the operations are defined below.

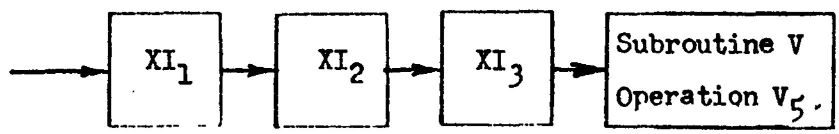

Figure G-11 - Subroutine XI for Electrical System Simulation

- XI_1 - Pilot turns off all nonessential equipment, which decrease the load on the battery that provides the essential d-c power.
- XI_2 - Pilot sets a-c power switch to INVERTER position, allowing the battery to provide essential a-c power through the inverter.
- XI_3 - Compute loads associated with both generator failures; these are the essential a-c and d-c loads.

L. Subroutine XII.

Subroutine XII determines whether engine rpm is at generator operating speed. The subroutine flow is given in Figure G-12, and the operations are defined below.

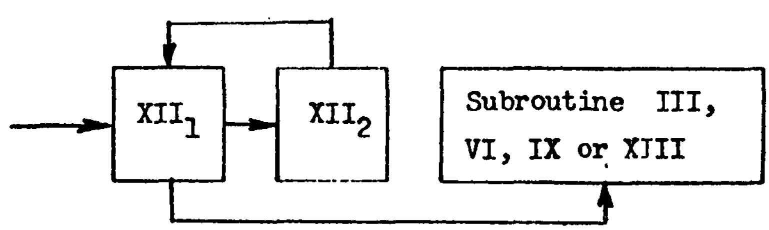

Figure G-12 - Subroutine XII for Electrical System Simulation

- XII_1 - Is engine speed at proper rpm to operate generators. The proper engine speeds for operating the generators can be obtained from the flight handbook.
- XII_2 - Adjust engine speed to generator operating requirement.

M. Subroutine XIII.

Subroutine XIII determines the condition of the first generator in a double a-c generator system. Figure G-13 is the flow chart; the operations are defined below.

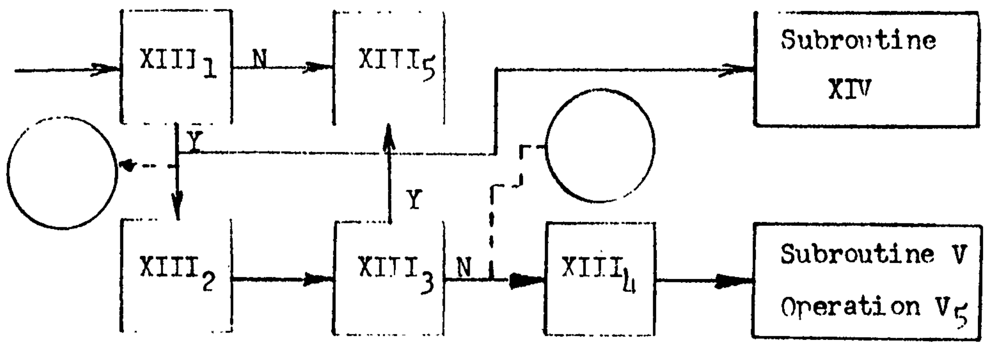

Figure G-13 - Subroutine XIII for Electrical System Simulation

- $XIII_1$ - Is instructor's fail switch associated with first generator on? Test instructor's fail switch associated with first generator.
- $XIII_2$ - Pilot reset procedure: set first generator switch to RESET and ON.
- $XIII_3$ - Did pilot reset procedure restore the first generator? If the failure is no more severe than an overvoltage or under voltage condition, the reset procedure can cause the generator to cut in.
- $XIII_4$ - Pilot sets first generator switch to OFF. This will cut out the failed generator completely and allow the second generator to supply the entire electrical system.
- $XIII_5$ - Compute normal load requirements for a double a-c generator system.

N. Subroutine XIV.

Subroutine XIV determines the condition of the second generator in a double a-c generator system. Figure G-14 is the flow chart, with the operations defined below.

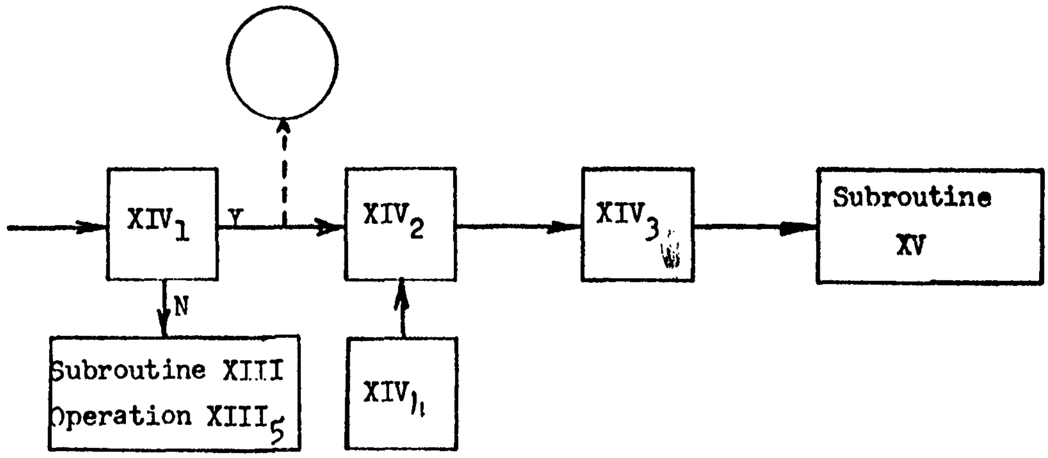

Figure G-14 - Subroutine XIV for Electrical System Simulation

XIV_1 - Is instructor's fail switch associated with second generator on? Test instructor's fail switch position associated with second generator.

XIV_2 - Pilot sets the emergency hydraulic pump handle to DOWN. The instructor has failed both generators. Emergency power is required. This procedure releases emergency power.

XIV_3 - Pilot turns off all nonessential equipment to conserve the output of the emergency generator.

XIV_4 - Input from hydraulic system. Hydraulic power is needed to extend the emergency generator.

O. Subroutine XV.

The availability of emergency power is determined in Subroutine XV, as shown in Figure G-15. The operations are defined below.

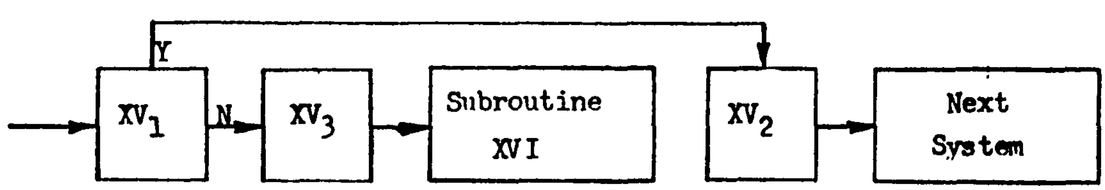

Figure G-15 - Subroutine XV for Electrical System Simulation

XV_1 - Is air speed less than 195 knots?
XV_2 - Emergency power available to emergency hydraulic pumps only. Air speed is less than 195 knots. All emergency power is diverted to the hydraulic pumps so that lateral control of the aircraft can be maintained.
XV_3 - Compute requirements of emergency loads for a double a-c generator system. Air speed is greater than 195 knots so that emergency loads can be computed.

P. Subroutine XVI.

Subroutine XVI determines whether either or both generators can be restored. The flow is charted in Figure G-16; the operations are defined below.

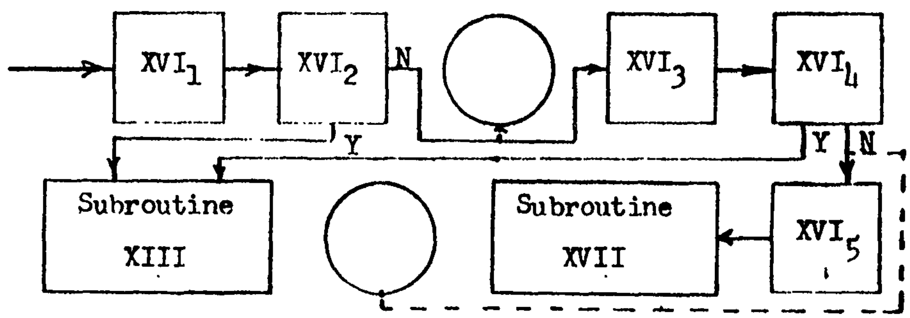

Figure G-16 - Subroutine XVI for Electrical System Simulation

XVI_1 - Pilot sets first generator switch to RESET and ON.
XVI_2 - Has reset procedure restored the first generator?
XVI_3 - Pilot sets second generator switch to RESET and ON.
XVI_4 - Has reset procedure restored the second generator?
XVI_5 - Retract emergency generator after 15-min continuous operation to prevent a decrease in generator output.

Q. Subroutine XVII.

Subroutine XVII determines whether the right generator alone can be restored. Figure G-17 is the flow chart; the operations are defined below.

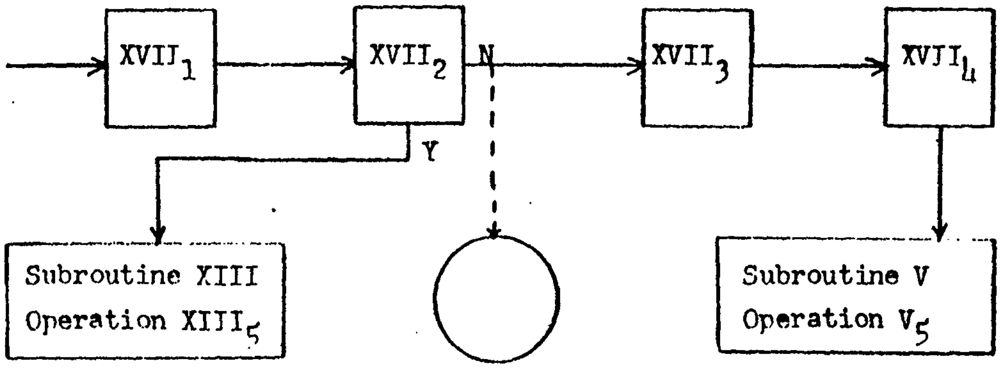

Figure G-17 - Subroutine XVII for Electrical System Simulation

$XVII_1$ - Pilot sets right generator switch to RESET and ON. While the emergency generator is retracted, the pilot can attempt to restore the right generator.

$XVII_2$ - Has pilot reset procedure restored the right generator?

$XVII_3$ - Pilot sets both generator switches to OFF. Right generator is not restored. With generator switches off, the generator is cut out completely.

$XVII_4$ - Pilot operates emergency generator intermittently. This is necessary only if the pilot cannot make an emergency landing in less than 15 min after emergency operation begins.

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